FACTORS AFFECTING THE ADOPTION OF SOIL ORGANIC CARBON ENHANCEMENT TECHNOLOGIES AND THEIR SPATIAL DISTRIBUTION AMONG SMALL-SCALE FARMERS IN KENYA AND ETHIOPIA

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A thesis submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in Land and water Management.

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DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

To my father, Mr. Maina, you showed me that I could dream big.
Thank you
To my mother, Mrs. Nyambura, you toiled hard to raise me well.
I love you.
To my wife Zanele and my daughter Nyambura, you allowed me to use your time to get here.
I love you
To my brothers and sisters, your support I appreciate with all my heart.

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LIST OF ABBREVIATIONS AND ACRONYMS

AICc	Akaike information criterion
AMP	Agricultural management practices
CBK	Central bank of Kenya
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GIS	Geographical Information Systems
GWR	Geographically Weighted Regression
IIRR	International Institute of Rural Reconstruction
INM	Integrated Nutrient Management
ISRIC	International Soil Reference and Information Centre
KALRO	Kenya Agricultural and Livestock Research Organization
KNBS	Kenya National Bureau of Statistics
LM	Land management
MOE	Ministry of education
NGO	Non-governmental organizations
NSWCP	National soil and water conservation project
OLS	Ordinary Least Squares
OM	Organic Matter
RF	Random Forest

RUSLE	Revised Universal Soil Loss Equation
SIDA	Swedish International Development Cooperation Agency
SOC	Soil Organic Matter
SOCET	Soil Organic Carbon Enhancement Technology
SSA	Sub-Saharan Africa
SSNPR	Southern Nations, Nationalities, and People's Region
SWC	Soil and Water Conservation
TFL	Tobler’s first law

ABSTRACT

Land degradation has poised great threats on food production and the sustainability of conservation areas. This has resulted from the depletion of soil organic carbon which forms the basis of soil fertility rendering farmlands unproductive. Efforts to resuscitate the productivity of farmlands have been made by the stakeholders promoting the adoption of soil organic carbon enhancing technologies (SOCETs). This study therefore, sought to investigate the extent of adoption of SOCETs and the factors affecting the adoption of these SOCETs among smallholder farmers and across the geographical space in the study areas in Kenya and Ethiopia. The dataset consists of 381 households in Ethiopia and 334 households in western Kenya. Probit model was used to predict the factors affecting adoption of SOCETs including fertilizer use, manure use, grass strips, crop rotation, intercropping, agroforestry and residue management. This was followed by the spatial modelling of the factors affecting adoption using Random forest to predict adoption spatially, and geographically weighted regression to show the relationship of adoption to each factor across space. The survey results indicated that fertilizer use was the most adopted technology in both Kenya and Ethiopia at 99% followed by intercropping at 80%, manure at 50 %, use of crop residues at 50%, crop rotation at 40% and grass strips at 30%. Factors constraining adoption were identified as those related to access of information, access to inputs and credit, household characteristics and biophysical characteristics such as rainfall, plot erosion and slope. Farmers who had access to information through extension ($p<0.01$) or involvement in farmer associations ($p<0.05$) and those who had access to education ($p<0.05$) had higher adoption of SOCETs. Those who lived closer to the markets ($p<0.05$) had higher adoption to fertilizer and agroforestry as compared to manure and grass strips. Farmers who perceived their soils to be fertile ($p<0.1$) had low adoption of SOCETs while those that perceived their plots to be susceptible to erosion ($p<0.05$) had low adoption to manure and fertilizers. Adoption prediction using the random forest model and further analysis using geographically weighted regression model showed that, factors affecting the adoption of SOCETs affect the farmers' decision differently across space. Access to information in an area leads to increased adoption to fertilizer which is discouraged by long distance to markets and difficult access to credit reducing adoption. Therefore, farmers with access to information and who live closer to markets had a higher adoption of SOCETs compared to those who live further away. The study therefore, recommends that the government should support the farmers' initiative by improving transport and market infrastructure. Also, the governments and the non-governmental organizations involved should invest in farmer education and dissemination of information so as to improve the knowhow of the farmers. Finally, the government should leverage micro-credit services to the farmers such as promoting affordable and appropriate credit facilities. The spatial aspect in the adoption of SOCETs should never be ignored by future research as it proves that failure to consider it would lead to wrong impressions and results.

Keywords: Soil organic carbon, Kenya, Ethiopia, sustainable land management technologies, land degradation**,** adoption**,** small-scale farmers

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

According to the World Bank (2013), agriculture is one of the most important sectors that can spearhead the development in Sub-Saharan Africa (SSA) since it sustains approximately 65 percent of the working population and about 32 percent of the continent's gross domestic product (GDP). Agriculture is also the most effective way of minimizing hunger, poverty, and the continued environmental degradation in the SSA (World Bank, 2013). Nevertheless, efforts to increase food production is a key challenge facing SSA, as traditional farming systems have proven to exacerbate land degradation and cause soil fertility losses. (Mwangana, 2016). Soil organic carbon (SOC) is termed as the basis of the fertility of the soil (Chan, 2008). It provides plants with nutrients that are essential for growth and development as well as in improving the soil structure, enhancing soil health and protecting the soil from toxic materials. SOC triggers soil formation processes such as the leaching of cations, soil acidification and gleying (including iron-reduction and podzolization) (Gaiser & Stahr, 2013). On average, SOC represents a limited weight of about 5% of the top most soil layers and decreases with the depth of the soil (Haynes, 2005). According to The Commonwealth Scientific and Industrial Research Organisation of Australia (CSIRO), rain forests or areas with good soils, consists of SOC levels which are in most cases more than 10%, compared to poor soils which have been deeply exploited and in areas where the SOC levels are in most cases less than 1% (Mackey et al., 2008). SOC levels are determined by various factors which include type of the soil, temperature of the area and the soil, rainfall, land management, and soil nutrition (Futurefarmers, 2008).

The key environmental challenge that leads to the continuous exhaustion of SOC is land degradation (Smith et al., 2016). It is caused by inappropriate agricultural practices and leads to the reduction of soil fertility through the loss of soil carbon, soil erosion, nutrient depletion, and includes all land degradation types which results in declining agricultural production and a reduction of suitable farmlands (Smith, 2016). Previous studies have recorded that land degradation patterns can be rectified by employing land use types that promote land regeneration and by adopting sustainable land management practices (Lal, 2015).

Agricultural management practices (AMP) that encourage the retention of stubble and continuous application of organic matter into the soil (Chan, 2008) boosts the SOC levels over the years (Smith et al., 2016). Their uptake leads to the buildup of SOC in arable soils (Lal, 2008). Campaigns to increase the adoption of AMP has been broadly executed in SSA so as to restore degraded lands and enhance agricultural productivity (Mango et al., 2017). Governments, non-governmental organizations as well as private entities have presented numerous soil and water conservation campaigns over the years. For instance, in Kenya, the National Soil and Water Conservation Project (NSWCP), in collaboration with the Swedish International Development Agency (SIDA), carefully chose Machakos district in 1974 to perform soil and water conservation projects. The campaign, which started in 1979, became a national campaign with the backing of the national government and the Ministry of Agriculture and Fisheries. Wolka (2014) recognizes the endeavors that have been underway in Ethiopia for almost forty years specifically on soil and water conservation initiatives. Along with these endeavors and investigations that have since been conducted with the purpose of enhancing SOC in both Kenya and Ethiopia (Gomiero, 2013), little has been undertaken to enlighten these institutions on the extent to which land management practices have been implemented in these countries and the factors constraining this adoption.

This study therefore, aims at ascertaining the extent by which technologies that encourage the intensification of SOC have currently been adopted by small-scale farmers in Western Kenya counties of Vihiga and Kakamega and in the Ethiopian highland watersheds of Yesir and Azuga suba. This study will utilize both descriptive and econometric analysis by carrying out household surveys and Probit econometric analysis to determine the factors that discourage adoption of Soil Organic Carbon Enhancement technologies (SOCETs), the trade-offs relating to these practices as well as the extent of farmer's use of these SOCETs. It will also apply Geospatial information systems (GIS) for further development of spatial relationships between the adoption of SOCETs and the anticipated factors known to influence the uptake of SOCETs.

1.2 Statement of the problem

Land degradation is a problem affecting populations globally but it is greatly severe in the SSA due to constrained land resources, rapidly rising population, change of land-use from natural land cover to agricultural and urban uses, in addition to the constant inability to tackle seasonal droughts and malnutrition (Lal, 1998). It lessens SOC affecting the overall quality of the soil directly together with its fertility and productivity (Dlamini et al., 2014). This in turn, poses a challenge to the sustainability of agriculture. Adoption of SOCETs reverses land degradation through the addition of nutrients to the soil, thus rebuilding the soil through amendments, re-establishment of vegetation, and buffering of soil acidity (Scherr & Yadav, 1996). Studies carried out to ascertain the adoption of SOCETs have acknowledged that, SOCETs have been extensively utilized in SSA to advance soil fertility (Mango et al., 2017). Governments, individual farmers as well as non-governmental organizations (NGOs) have continued to champion the utilization of SOCETs. For instance, Western Kenya, the Kenyan economy's breadbasket (Mukoye et al., 2016), has had the highest level of government and development NGOs coverage of agricultural projects. Since the 1970s, Ethiopia on the other hand, has made continuous efforts to initiate sustainable land management practices aimed at escalating agricultural development and ensuring sustainable use of natural resources. (Miheretu & Yimer, 2017). As early as 1980s the Ethiopian government had introduced novel technologies for land conservation through the assumption of food for work incentives (Shiferaw and Holden 1998). Notwithstanding the efforts of the government and the NGOs to intensify the uptake of SOCETs, adoption of these technologies by the small-scale farmers remains low (Nigussie et al., 2017). This is due to the fact that the adoption of SOCETs is affected by significant biophysical and socio-economic characteristics, which are unique to each plot, specific to each farmer and, in other cases, location-based (Bisaro et al., 2011). Gauny (2016) reported that such characteristics serve as obstacles to the adoption of soil SOCETs. The farmers' choice to adopt or not to adopt to a particular SOCET is also influenced by trade-offs associated with these technologies.

The state, policy makers, NGOs and funding bodies in both Kenya and Ethiopia have limited knowledge on the extent to which small-scale farmers have adopted SOCETs. They also have a lack of knowledge on factors affecting the extent to which different land management practices are adopted by farmers. While restoration interventions are underway, the positive results reported are lower than anticipated and the required studies have not been clearly carried out and understood prior to the implementation of these interventions (Mugume, 2014). Very few studies have been performed in Kenya and Ethiopia to analyze the factors affecting the extent to which SOCETs have been adopted. The goal of this study is therefore to fill this gap and, as a result, to provide facts on the factors that negatively affect the extent of the adoption of SOCETs and their spatial distribution in western Kenya and Ethiopia.

1.3 Justification

This study will be important as it will try to determine the extent to which SOCETs have been adopted by farmers and the factors that impede their adoption. It would advise policy makers on prioritizing land management practices and the difficulties that need to be resolved before encouraging farmers to embrace SLM practices. It will advise the government on the factors to be addressed in order to ensure the implementation of SOCETs and thus contribute to the practice of improved agriculture to resolve the food insecurity issue. It will also advise policymakers to introduce the most effective intervention plan in the study areas and guide funding agencies in the process of engaging farmers of the research areas so as to find out everlasting strategies for soil fertility depletion and consequently, soil degradation. Solutions should be found based on the constraints of implementing SOCETs. These will be made available to farmers in order to promote the adoption of these practices and, subsequently, increased SOCETs adoption.

1.4 Research objectives

The study aims at generating knowledge that can be used by policy and decision makers in making rational choices when promoting the adoption of soil organic carbon enhancement technologies among small-scale farmers of Kenya and Ethiopia.

The specific objectives are;

1. To assess the extent of the adoption of soil organic carbon enhancement technologies among small-scale farmers in Kenya and Ethiopia.
2. To establish the key socio-economic and biophysical constraints to adoption of soil carbon enhancement technologies.
3. To map the factors affecting the adoption of soil organic carbon enhancement technologies.

1.5 Hypothesis

1. The extent of adoption of SOCETs among the small-scale farmers in Kenya and Ethiopia is very low.
2. Site specific biophysical and socioeconomic factors do not influence farmer’s decisions to practice the technologies that increase soil organic carbon.
3. The factors affecting the adoption of soil organic carbon enhancement technologies by small-scale farmers cannot be mapped spatially.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Land degradation in SSA and across Kenya and Ethiopia

Land degradation generally is the decrease in the soils ability to support the requirements of biotic species as well as human needs (Lal, 2009). This could be either physically, biologically, chemically or ecologically (Lal, 2015). The land degradation process is caused mainly by human-induced factors of unsuitable land use and lack of soil management practices that aggravate the soil erosion cycle and other processes of land degradation. This is attributed to a decline in ecosystem services. In addition to this, it reduces agricultural yields, of which 50%-70% of the population of Africa depends on for their livelihood (Jama et al. 2011). Organic matter (OM) and vegetation cover when stabilized can enhance soil resistance to erosion (Berhe et al., 2007).

Most areas of western Kenya consist of a high population density of around 500-1200 persons per square kilometer. Since this population is dependent on farming for their own needs (subsistence), they have chosen to expand their farmlands and during this process they enhance land degradation (Morera, 2010). Unacceptable practices that degrade the environment include; deforestation, expanded farming of conservation areas and intensive grazing without allowing regrowth. Such practices facilitate soil erosion which leads to soil degradation, biodiversity loss and water degradation. Land deterioration is among Ethiopia's most significant global environmental setbacks where it is caused by population pressure and intensive cultivation on fragile lands and on steep slopes while employing inappropriate farming methods (Tadesse & Belay, 2004). The most important cause of land degradation is soil erosion. Soil erosion takes place in the Ethiopian highlands especially in areas above 1500 metres above sea level (m.a.s.l). These highlands represent 45% of the entire country (Tadesse & Belay, 2004) and sustains 80% of the population with 95% of the farmlands found here and 75% of the Ethiopian livestock population thriving in these highlands (Shiferaw and Holden, 1998).

2.2 Reversing land degradation

Soil organic matter could be regenerated during the early agrarian periods using fallowing during the shifting cultivation (Snapp et al., 1998). However, shifting cultivation and fallows are no longer possible due to the increased population which has resulted to reduced land for cultivation

(Nkamleu, 1999). Therefore, approaches should be practiced that help reverse land erosion and increase soil organic matter (Gockowski et al. 2000). Monique and Sasha (2016) acknowledge the value of preventing and reversing land loss using SOCETs. It is possible to reverse land degradation by encouraging the uptake of most effective SWC techniques, with substantial opportunities for successful implementation and sufficient policy access (Koning et al., 2001). Lal (2015), records that, trends in soil degradation that include SOC depletion can be reversed through the use of recommended practices for land management. Increasing SOC pool translates into an increased soil quality and decreases the risks of land degradation in return (Lal, 2015).

Interventions including conservation agriculture, promoting constant vegetation cover such as, controlled grazing at optimal stocking rates at a particular site, integrated soil fertility management, planting cover crops and mulching contribute to an improvement in SOC and soil quality regeneration (Lal, 2015). Montgomery (2007) notes that residues, which form part of the soil's OM, if left on the ground to form mulch increases water absorption and decreases runoff and erosion. The residues also form the organic carbon component of the soil later on. Agricultural practices like organic farming and minimal tillage can help minimize the loss of soil and restore the fertility of the soil (Lal, 2010; Carr et al.,2013).

2.3 The depletion of Soil organic carbon

Continued transformation of conservation areas (pasturelands and forests) to farmlands, along with poor management of land (inappropriate agricultural practices and insufficient residue management), has resulted into decreased SOC and the fertility of the soil (Wiesmeier et al., 2016; Godde et al., 2016). Montgomery (2007) observed that unsuitable farming techniques exacerbate the erosion of the soil and leads to the depletion of SOM resulting in reduced soil fertility that undermine yields. Lal, (2003) found out that mineralization and soil erosion cause the SOC pool to become acutely depleted. The author also predicts the amount of total SOC lost through erosion processes after considering a delivery ratio of approximately 10% and a SOC stocks range of between 2–3%, 4.0–6.0 Pg / year and this loss can be accompanied by a 20% emission emanating from the mineralization of the displaced carbon. This leads to a further loss of 0.8–1.2 Pg C / year from our planet.

The anthropogenic activity resulting in the conversion of forests and grasslands for agricultural production is one of the major reasons for the ongoing depletion of SOCs. Lal, (2004) states that this transformation promotes SOC degradation in temperate soils with up to 60 percent and tropical soils with 75 percent. The adoption of SOCETs which decrease the risk of C emissions and sequesters C in soil and biota is the solution to this problem.

2.4 Increasing SOC content of the soil

Research has established that management practices aid in soil carbon reduction and restoration (Franzluebbers, 2010). Such activities, besides preventing soil depletion, preserve soil carbon reserves contributing to increased sequestration capacity for soil carbon (Silver et al., 2007). These practices include for instance, contour farming, agroforestry, animal control to prevent overgrazing and adding lime to the soil to balance the pH of soil in these acidic soils. Improved soil carbon sequestration is known to be triggered by various crop and soil management technologies. Dahal and Bajracharya, (2010) reports these technologies to include minimum tillage and no tillage cultivation with the utilization of mulch and planting cover crops, integrated nutrient management (INM), use of organic and inorganic fertilizers in a balanced application, crop rotations and agroforestry, and improved rangelands with controlled rates of animal stocking. Recent studies show that SOCETs can improve yields by enhancing food protection and preventing potential degradation of land (Branca et al., 2013). Snapp et al. (1998) reported that land management activities must be very effective in enhancing food health, reducing risks and increasing the fertility of the soil.

2.5 Soil organic carbon enhancement technologies in Kenya and Ethiopia

The adoption of SOCETs in the SSA began in the era of colonization and continued following the government's efforts to reduce erosion through the use of SWC and SOCETs to enhance soil fertility (Liniger et al., 2011). For example, in Lesotho the highlands had already been covered by 1960 using buffer strips; roughly, 118 000 km of bunds were constructed in Malawi between 1945 and 1960 on an area of about 416 000 ha; and half of the rural agricultural land in the eastern province was covered by the use of contour strips in Zambia by 1950 (Beinart, 1984). Kenya has had a long history of SWC and land and water management intervention by the government, as stated by Pretty et al. (1995). Such steps had already been adopted by the colonial government since the 1930s but implementation was not easy because they were so tainted by forced labor during colonization that administrators shied away from popularizing it (Pretty et al., 1995). It has been reported that ecosystem health and resilience are strongly affected by the management methods we follow, as well as the changes in the climate (Monique and Sasha, 2016). According to Schmidt & Tadesse (2019), Ethiopia on the other hand, has experienced major threats associated with extreme land degradation leading to a decline in agricultural yields and GDP. Thus, in order to reduce soil erosion and nutrient loss, the Ethiopian government has over the years launched programs aimed at Ethiopia's productive agricultural highlands such as the Sustainable Land Management Program (SLMP), which in 2009 targeted 209 woredas (districts) in six regions of the country.

2.6 Factors that influence the adoption of SOCETs

A collection of biophysical and socio-economic factors influences the preferences of the farmers to accept or reject a new SOCET at any given time and space (Tadesse & Belay, 2004). Such factors vary from location to location, leading to a varying rate of acceptance of these activities across regions. According to Rezvanfar et al., (2009), there are many factors that dictate the adoption of farmers to any land management technology. The factors are classified into two groups which include the personal attributes of the farmers, e.g. age, farming experience, knowledge level, education, ease of access to information etc. and plot level characteristics such as plot size, land tenure, income etc. A study conducted in Cameroon on the status of agroforestry adoption and factors affecting the adoption of agroforestry by farmers (Nkamleu & Manyong, 2005), recognized family size, gender of the household head, level of education, experience of farmers, membership of farmers to groups and associations, access to extension, off-farm income, land tenure protection, agro-ecological zone and distance to nearest market as some of the factors affecting its adoption. A study conducted in Brazil (De Souza Filho et al., 1999) identified that there was a high probability that a farmer would adopt sustainable farming practices if they were associated with farmers' associations, if they were connected to non-governmental organizations, if they had enough labour and if their farm was situated in a position with favorable soil conditions. Marenya & Barrett (2007) discovered that the adoption of SOCETs to increase soil productivity and manage natural resources is constrained by resource constraints such as farm ownership size, livestock value, family labour availability, educational achievement, off-farm income and household head gender.

2.7 Trade-offs in agriculture

The decision-making process involves the selection of different options and encompasses trade-offs in the daily operations (Barrowclough, 2016). According to Klapwijk et al., (2015) trade-offs comprise interactions that are prevalent particularly when land is handled with numerous value chains. Trade-offs are considered to be very consistent when resources are scarce and the stakeholders' interests clash (Giller et al., 2008).

There are different forms of trade-offs within agriculture (Erenstein, 2015). These include crop-related trade-offs (grains or residues), (milk or meat), fields (food or groundwater quality correlated with nitrate leaching), farms (development of multiple competing crops) and ecosystems (agricultural production versus soil for nature) (Klapwijk et al., 2015). The key determinants of trade-offs and adoption are classified into activities or technologies that have either an agronomic or environmental impact (Tittonell et al., 2015). Agronomic impacts include measures to boost yields while measures to eliminate degradation constitute environmental impacts. Rainfed areas are known to encounter resource insufficiency, and therefore small-scale farmers are faced with several trade-offs relating to crop biomass residues (Tittonell et al., 2015). These may include the percentage of residues that are fed to livestock as fodder, the percentage used to increase soil fertility, the percentage used as fuel and in some cases as building materials or sold for income. Gauny (2016) records that biomass residue trade-offs affect farmers' choices and may turn into the adoption of land management activities associated with farm retention of crop residues.

2.8 Extent and intensity of adoption of sustainable land management technologies

The quantity of SOCETs adopted by farmers is taken to mean the intensity of adoption and the diversification of the technologies (Sharma et al., 2011). In studying the intensity of the uptake of SOCETs scientists noted that various technologies adopted relate with each other and that no constraints are put in place for the quantity of SOCETs applied on farm as long as the last one to be taken up is beneficial (Lohr & Park, 2002; Isgin et al., 2008). The extent is dependent upon the size of the area that a chosen technology occupies. It is the proportion of the land occupied by a SOCET at the farm level in which a farmer chooses to adopt on the basis of some biophysical and socioeconomic factors.

2.9 Mapping of factors affecting adoption of SOCETs

According to Tobler's first law (TFL) of geography, everything across space has a relationship with everything else, nonetheless, things that are closer to each other are more related than those further away (Leitner et al., 2018). Therefore, there exists spatial relationships between the adoption of SOCETs and the factors that affect farmers' adoption of SOCETs and therefore their influences on the farmers' choices to adopt. The probability of spatial heterogeneity when evaluating the factors that influence farmers' adoption of SOCETs is highly significant because farmers are influenced by the behavior of neighboring farmers, opportunities provided by the enabling environment or by agro-ecological characteristics as they try to make decisions on whether to adopt to a technology or not (Langyintuo & Mekuria 2008). Ignoring spatial heterogeneity can lead to obtaining biased or inefficient results (Haining, 2015).

CHAPTER THREE

Factors affecting the adoption of SOC enhancement technologies among small scale farmers in Kenya and Ethiopia.

3.1 Abstract

Declining soil fertility is one of the major causes of reduced food production leading to food insecurity, high levels of poverty and underdevelopment in sub Saharan Africa region. To improve soil fertility, the uptake and implementation of soil organic carbon enhancement technologies (SOCETs) have become crucial in reversing and preventing land degradation, improving agricultural productivity through enhancing soil organic carbon (SOC) which is the basis of soil fertility. Using data from 334 farming households in Western Kenya counties of Vihiga and Kakamega, and 381 households in the Ethiopian watersheds of Azuga-suba and Yesir, the study explores the extent of adoption of the SOCETS technologies that enhance SOC including; manure, intercropping and crop rotation, agroforestry, addition of fertilizer and crop residue management to ascertain farmer adoption rate of the technologies in improving soil fertility. Using Probit model the study tries to find out the constraints to adoption of these technologies. The results of the study indicate that fertilizer is the most adopted technology having over 90% adoption both in Kenya and Ethiopia. Others were manure with 55%, 40%, 28% and 56% in Vihiga, Kakamega, Angacha and Bure respectively, intercropping at 77% and 76% in Vihiga and Kakamega respectively with crop rotation in Ethiopia having being adopted in 0.09% and 44% in Angacha and Bure respectively, grass strips has been adopted in 32%, 39%, 33% and one percent in Vihiga, Kakamega, Angacha and Bure respectively while crop residue management has been adopted in 26%, 51%, 37% and 26% in Vihiga, Kakamega, Angacha and Bure respectively. The results further indicated that the adoption of SOCETs is highly constrained by; lack of education at $p<0.05$ with a mean grade level of household heads at 1.67, extension at $p<0.01$ with mean of farmers with access at 64% and credit services at $p<0.01$ with mean of access at 38% and which are influenced by institutions and local farmer groups. Other constraints include; large plots in manure and fertilizer addition, small plots in agroforestry and grass strips adoption at $p<0.1$ with mean acreage at 0.75 acres, land tenure insecurity in agroforestry, manure and residue management at $p< 0.1$ with 50% lacking tenure security and factors relating to farmers' perceptions such as erosion at $p<0.05$ with mean of 74% perceiving soil erosion is a problem and soil fertility at $p<0.1$ at the mean of 73%. These results imply that strengthening of institutions that enhance farmers' knowledge and provide credit as well as service providers and strengthening of social protection schemes and farmer groups should be done.

Keywords: sustainable land management, adoption, soil organic carbon, Kenya, Ethiopia, small scale farmers

3.2 Introduction

According to the Food and Agricultural Organization, (2011), Agriculture contributes 26% of the Kenya's Gross Domestic Product (GDP) and 27% indirectly by public and private sectors. It provides employment to more than 40% of the Kenyan population and more than 70 per cent of the population in the rural areas. In Ethiopia, agriculture accounts for 46.3% of GDP, with exports amounting to 83.9%, and employs more than 80% of the population (Honda et al., 2008). Soil degradation which is the main cause of decreased agricultural production results from anthropogenic factors leading to poverty, hunger, malnutrition and even death (Gomiero, 2016). This results from a rapidly increasing population without a counter mechanism to increase food production to sustain the additional population leading to an increased demand for food which in turn translates to farmers practicing continuous cropping on their farmlands and also the expansion of the agricultural lands into marginal lands (FAO, 2017). As a result, this increases pressure on farmlands, depleting soil nutrients and rendering the soil unproductive.

Reduced soil fertility is attributed to reduced or low soil organic carbon. Soil organic carbon (SOC) is a constituent of soil organic matter (SOM) that can be measured. Approximately between 2–10% of the soil's mass is made up of organic matter. OM performs a vital role in the agrarian soils by enhancing their chemical, biological and physical performance (Griffin et al., 2013). SOM is mainly the result of organic matter inputs less losses, and is usually impacted by climate, soil type and land use management (Angers et al., 1997). SOM enhances nutrient retention and turnover, supports the structure of the soil, enhances water retention and availability in the soil, enhances sequestration of CO_2, assists in the degradation of pollutants, and increases the resilience of the soil (Allison, 1973). SOM rises significantly whenever the proportion of inputs in terms of residues, is higher than the proportion of losses. Inputs are determined by plant residue production, but in some cases may result from the addition of amendments to the soils or animal by-products. Losses of SOM occurs due to various reasons such as decomposition and soil erosion (Viscarra et al., 2014).

Increasing SOC therefore, is principal to increasing the soil fertility and productivity and consequently reducing poverty and malnutrition. This can be done by adopting soil organic carbon enhancing (SOCE) technologies that enhance stubble retention onto the farmlands, covers the soil and reduces loss of soil and organic matter through erosion. SOCETs encourages carbon sequestration in the soil leading to the creation of a carbon sink (Kern and Johnson, 1993; Paustian et al., 1997). Dahal and Bajracharya, (2010) documents these technologies as minimum tillage and no tillage farming with the application of mulch and planting cover crops, integrated nutrient management (INM), applying inorganic and organic fertilizers in a balanced application, crop rotations and agroforestry, and improved rangelands with controlled rates of animal stocking.

Despite the many benefits associated with the adoption and application of these SOCETs as well as the considerable efforts carried out by the government, national and international organizations aimed at encouraging farmers to invest in them, the extent of adoption remains low (Ngongo, 2016; Teklewold et al., 2013). In Ethiopia for instance, numerous soil and water conservation technologies have been invested on to curb land degradation but the adoption remains low. In Kenya, through Kenya Agricultural and Livestock Research Organization (KALRO) and agricultural university research centers, the government together with private development partners have facilitated and introduced various soil and water conservation technologies through state and private funded agricultural research activities but the spread and extent of adoption of these technologies remains very low. Ingold, (2002) observed that failure of small-scale farmers to accept, apply and adopt land management technologies aimed at increasing productivity in their farms has led to extremely low agricultural productivity. This has led to increased food insecurity, poverty, hunger and malnutrition in SSA. The extent of land management technologies adoption is influenced by an array of factors which have been largely categorized into; social, economic and institutional factors (Mamudu et al, 2012). Adoption of SOCETs by smallholder farmers has been challenged by a variety of environmental, social, economic and political characteristics explicit to the setting within which they are being adopted (Bisaro et al., 2011; Cordingley et al., 2015) .The economic factors which have been identified include land size, the underlying expense of a technology or its anticipated advantages compared to the cost incurred in adopting a technology and the farmers' financial state derived from off-farm undertakings (Dessart et al., 2019). Social factors that influences the possibility of a farmer adopting to a technology include; age, level of education, sexual orientation and social groupings (Kinyangi, 2014). Institutional variables that determine uptake of SOCETs by farmers include; access to information, government policies and access to the extension services delivered (Kinyangi, 2014). There is a need to speed up the rate of adoption of land management technologies that enhance soil organic carbon to improve food security. This therefore, call for a requirement of knowledge and understanding of the factors that constrain the small-scale farmer's decisions to adopt to these technologies. This study sought to establish the extent of adoption of the SOCETs and the factors influencing the adoption of these technologies by smallholder farmers in Kenya and Ethiopia in bid to increase SOC and consequently soil fertility.

3.3 Materials and methods

3.3.1 Description of the study site

This study was conducted in Vihiga and Kakamega counties in western Kenya (figure 3.1) and the watersheds Yesir and Azuga-suba in Ethiopia (figure 3.2). Vihiga county lies between longitudes 34º 30´ and 35º 0´ East and latitudes 0º and 0º 15´ North and covers an area of 531km² with a population density of 1045 persons per km², while Kakamega county lies between longitudes 34° 20′ and 35° 09′ East and latitudes 0° 05′ and 0° 53′ North and covers an area of 3225km² with a population density of 544.3 persons per km². On the other hand, Yesir watershed lies between longitudes 37° 02′ and 37° 07′ East and latitudes 10° 35′ and 10° 48′ North and covers an area of 115.8km² with a population density of 158 persons per km², while Azuga-suba watershed lies between longitudes 37° 48′ and 37° 55′ East and latitudes 7° 15′ and 7° 26′ North and covers an area of 88.7km² with a population density of 502.13 persons per km².

The climate of Vihiga county consists of an annual average rainfall of between 1,800mm and 2,000 mm with an average temperature of 24°C and the soils are mainly Acrisols and Cambisols while that of Kakamega county consists of an annual average rainfall of between 1,250mm and 1,750mm with an average temperature of 21°C and the soils are predominantly luvisols and lixisols. Yesir watershed on the other hand receives an annual average rainfall of between 713mm and 2832 mm with an average temperature of 19°C with Luvisols, Leptosols and Verstisols being the main soils while, Azuga suba watershed receives an annual average rainfall of between 900mm and 1750 mm with an average temperature of 20°C with dominant soils being Vertisols and Luvisols.

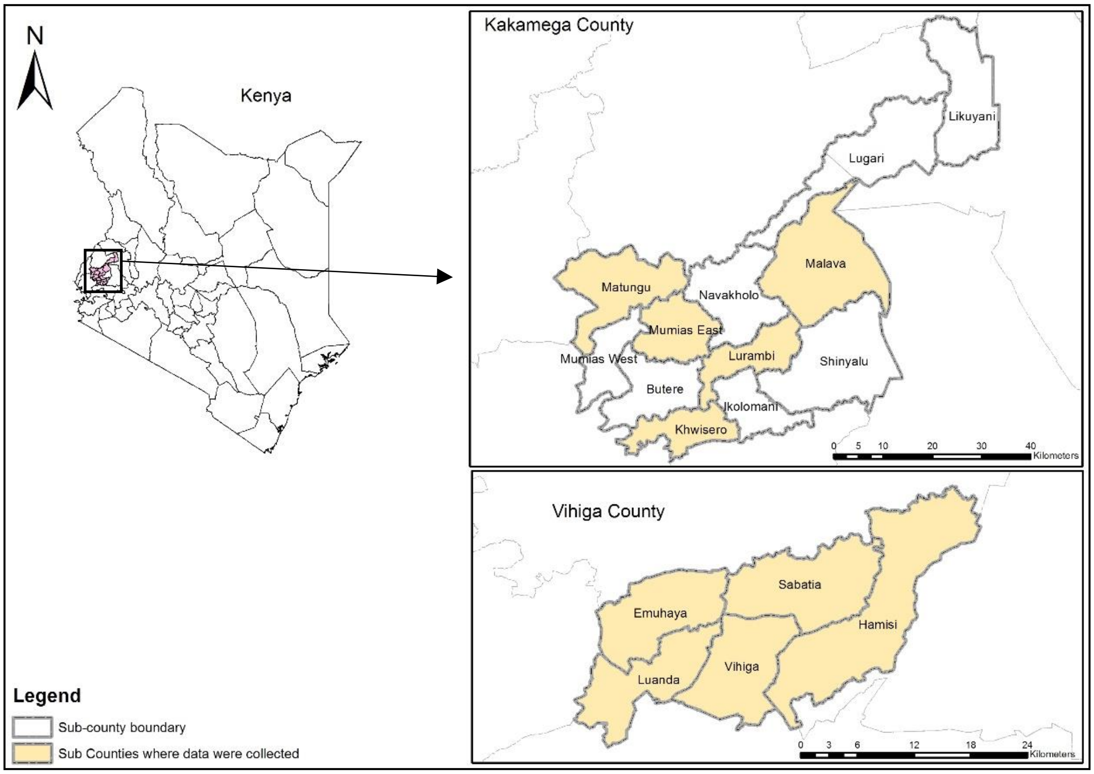

Figure 3.1. Location map of the study areas in Kenya

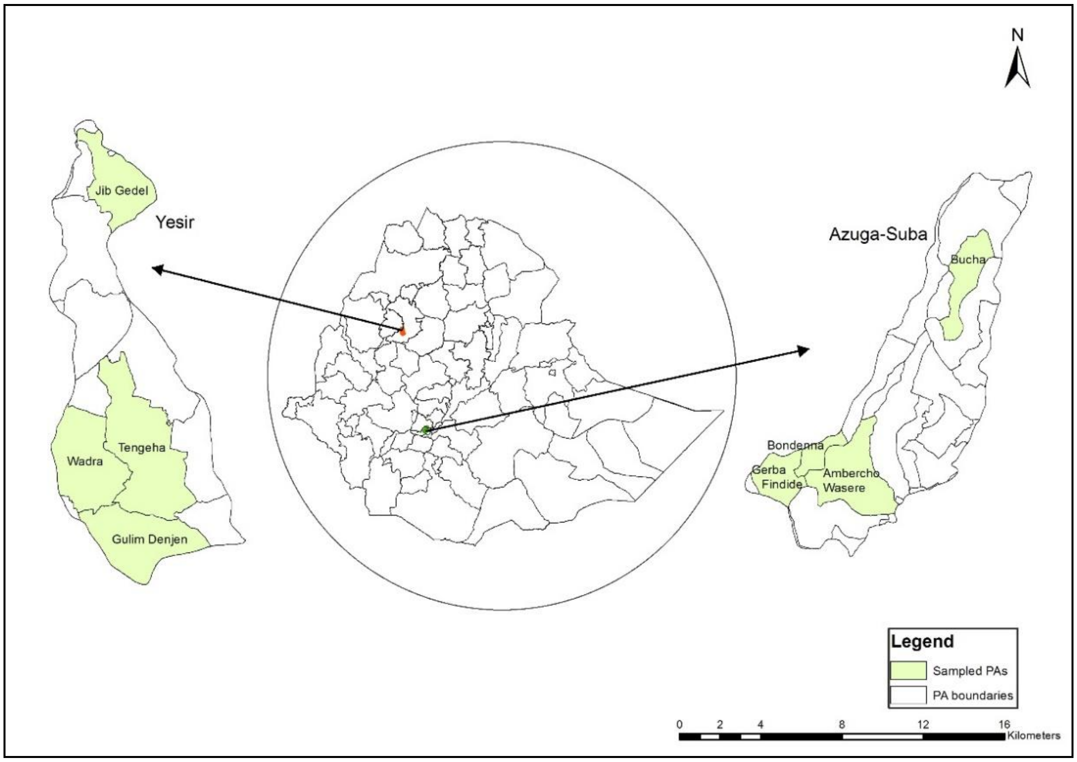

Figure 3.2. Location map of the study areas in Ethiopia

The population in these areas practice a mixed system of crop and livestock keeping in which crop and livestock mutually benefit one another. Various crop management practices associated with these areas include application of manure sourced from the livestock kept, crop rotation which is common in Ethiopia and intercropping which is a common practice in Kenya.

The most common crops in Vihiga and Kakamega include maize and beans while in Yesir and Azuga suba is teff, barley, wheat and horse beans (Bakela). These crops are grown mostly for subsistence purposes. Other important crops include; potatoes, bananas, peas, tea and coffee in Western Kenya and maize, sorghum, finger millet, Enset, pulses and oil crops in Yesir and Azuga suba. Cattle, goats, sheep and poultry forms the major types of livestock kept. In addition to these donkey, horses and mules are also common in Yesir and Azuga suba. All the study areas experience bimodal types of rainfall with western Kenya experiencing the long rains during March to May season and the short rains during October to December season. Ethiopia, on the other hand, experiences the main season (***meher***) between June and September while the short rainy season (***belg***) is experienced between February and April (Lung'aho, 2016).

Major economic activity in the study areas is rain fed agriculture. Western Kenya is known to be the grain basket of Kenya. However, in the current times the area has been affected by low productivity due to land size reduction, land degradation, erratic and unreliable rainfall and prevalence of pests and diseases. As a result, farmers are opting for off-farm income by leaving their farms to work in other farms and manufacturing industries.

3.3.2 Field survey

This part describes the process carried out for the purpose of data collection from the questionnaire development, household sampling to the data collection and analysis.

3.3.2.1 Sampling Technique

The sampling frame comprised of smallholder farmers of Vihiga and Kakamega counties of Kenya and those of Ethiopia watersheds of Yesir and Azuga-suba. Focus group discussions were carried out before the actual data collection to enable researchers develop an all-inclusive questionnaire.

In sampling the households to undertake the survey, both purposive selection and multi-stage random sampling were adopted. The first stage involved the purposive selection of 2 counties in Kenya i.e. Vihiga and Kakamega and 2 watersheds of Ethiopia which are, Yesir and Azuga-suba. The multi-stage sampling procedure was applied as follows: In Kenya, the first stage involved the random selection of 5 sub-counties from Kakamega County to form primary sampling units. These were Malava, Mumias-East, Lurambi, Matungu and Khwisero. In Vihiga County all the sub counties (5 in number) were studied. These were Sabatia, Emuhaya, Hamisi, Luanda and Vihiga. The second stage involved selection of 3 wards from each selected sub county. Using simple random sampling method, 10 farm households were selected from each ward to reach 150 farmers per county, 10 farmers were added to cater for precautionary purposes adding up to 160 farmers. In Ethiopia, a similar procedure was used with the first stage involving random selection of Pastoral areas (PAs) also known as Kebeles, followed by a random selection of villages from each selected PA. In Yesir watershed, the PAs were Gulim, Jib Gedel, Tengeha and Wadra while in Azuga-suba watershed the selected PAs were, Ambercho Wasere, Bondenna, Bucha and Gerba Findide. A list of households in the two watersheds was drawn, and sample households were randomly selected totaling to 160 for each watershed. In Ethiopia, the ultimate sample size increased due to the requirement for more correction data reaching 219 observations in Yesir watershed and 162 in Azuga-suba watershed. In Western Kenya, an additional of 14 households were collected. The ultimate sample size therefore was 334 households in Western Kenya and 381 households in Ethiopia. Internal farm divisions by individual farmers to plots led to a total of 1027 plots in western Kenya and 2610 plots in Ethiopia.

During data collection, the targeted respondents were the household heads but in case they were absent, a member of the household with a good knowledge of the head was identified to stand in as the respondent.

3.3.2.2 Data and data Sources

Using a structured questionnaire, quantitative and qualitative data was collected. Key informant interviews as well as focus group discussions were conducted before the study. The information that was gathered during the survey included; households' demography characteristics, household wealth indicators, livestock holding, plot level data, agricultural technologies and activities, inputs use, marketing activities, households' accessibility to markets, households' accessibility to credit services and households' access to extension and training.

3.3.2.3 Dependent and explanatory variables

The data that were collected has been summarized into dependent and explanatory variables in table 3.1. The data is presented at a plot level where household size was measured as the number of household members who lived and ate in the same household, distance to the plot and to the market was measured as the time taken to walk in minutes to the plot or to the market while proper residue management was measured by noting that the farmer left more than 30% of their crop residues on their plots after harvesting.

Table 3.1 Key variables for households in Kenya and Ethiopia

	Kenya				*Ethiopia*			
Dependent variables (1=Yes; 0=No)	Mean	S.D.	Min	Max	Mean	S.D.	Min	Max
Technology adoption								
Agroforestry	0.68	0.47	0.00	1.00	0.003	0.06	0	1
Grass strips	0.35	0.48	0.00	1.00	0.15	0.36	0	1

Manure	0.47	0.50	0.00	1.00	0.43	0.50	0	1
Crop rotation					0.24	0.43	0	1
Fertilizer use	0.94	0.24	0.00	1.00	0.95	0.23	0	1
Intercropping	0.76	0.42	0.00	1.00				
Residue management	0.39	0.49	0.00	1.00	0.31	0.46	0	1
Explanatory variables								
Plot level variables								
Slope (degrees)	17.16	0.00	0.10	17.16	3.73	3.19	0.11	20.8
Tenure security of the plot	0.50	0.50	0.00	1.00	0.84	0.37	0	1
Soil erosion perception	0.74	0.44	0.00	1.00	0.24	0.43	0	1
Plot size (acres)	0.75	0.71	0.01	5.00	0.61	0.57	.00025	6.18
Distance to plot (minutes)	5.20	19.80	0.00	360.00	17.04	23.03	0	210
Plot fertility perception	0.73	0.45	0.00	1.00	0.92	0.28	0	1
Socioeconomic variables								
Education level of household head (grade/level)	1.67	1.03	0.00	4.00	2.61	1.04	1	5
Livestock ownership	0.98	0.13	0.00	1.00	0.98	0.14	0	1
Household years in farming	23.02	15.33	0.00	68.00	25.95	11.72	2	60
Household size	5.40	2.41	1.00	15.00	6.60	2.13	1	13
Distance to urban market (minutes)	111.39	75.57	10.00	420.00	88.62	54.17	7	240
Institutional characteristics								
Credit access	0.38	0.49	0.00	1.00	0.28	0.45	0	1
Access to extension	0.64	0.48	0.00	1.00	0.79	0.41	0	1
Group membership	0.63	0.48	0.00	1.00	0.57	0.50	0	1
Climatic characteristics								
Annual precipitation (mm)	1860	69.32	1686	2005	1441	227.82	1105	1828

The Dependent variables

This part includes the seven SOCETs as presented in Table 3.1 as descriptive statistics. The data presented is adoption data. The first SOCET is Agroforestry. According to FAO (2015), agroforestry refers to land-use systems involving woody perennials purposefully being grown with agricultural crops and/or animals on the same piece of land. The second SOCET is Grass strips where farmers plant grasses along the contour in arable farms to minimize soil erosion and runoff (Abena et al., 1992). The third SOCET is Crop rotation. According to FAO, Crop and Grassland Service (2003) crop rotation is the act of growing a progression of various types of crops in the same area subsequently. The crops are rotated in different plots with seasons. The fourth SOCET is fertilizer use which involves addition of chemical elements into the soil to supplement for the missing soil nutrients in a crop plot. The fifth SOCET is intercropping which involves the growing of crops of various ecological needs and stress reaction attributes together. The sixth SOCET is the addition of manure which involves the application of animal waste in on the crop plot. The seventh SOCET is residue management which involves leaving crop residues from the previous season after the harvest in order to improve the soil's physical and chemical properties (McSorley & Gallaher, 1994).

The explanatory variables

Variables describing plot level characteristics

Plot specific variables include plot slope, tenure security, soil erosion perception, size and soil fertility perception of the plot and distance to the plot. From this data farmers are seen to work on plots which are about 0. 0001–2.5ha in Ethiopia and 0.01 – 5ha in Kenya in terms of size. The plot slope ranged between 0.1 degrees to 17.16 degrees in Kenya and to 20.8 degrees in Ethiopia. Distance to the plots ranged between zero for those who lived on their farms to 360 walking minutes in Kenya and 210 walking minutes in Ethiopia. 73% of the respondents in Kenya and 92% in Ethiopia perceived their soil to be fertile, 74% of the respondents in Kenya and 24 % in Ethiopia perceived erosion to be a problem in their plots while 50% of the respondents in Kenya and 16% in Ethiopia lacked tenure security.

Socioeconomic variables

Socioeconomic variables that were considered in this study include; Distance to urban market, education level of household head, livestock ownership, household years in farming and the size of the household. Distance to urban market ranged between 10 and 420 minutes in Kenya and 7 and 240 walking minutes in Ethiopia. 44% of the household heads in Kenya and 19% in Ethiopia had gone through secondary education while 98% of the households in both Kenya and Ethiopia owned livestock. Households' years in farming ranged from 1 to 68 in Kenya and 2 to 60 years in Ethiopia while the size of the household ranged between 1 and 15 members in Kenya and 1 and 13 members in Ethiopia.

Institutional characteristics

Institutional characteristics that were taken into account in this study were farmers' access to credit, access to extension and membership of the household in farmer groups and associations.

Climatic characteristics

Climatic characteristics considered in this case was only annual precipitation/ rainfall. Precipitation affects soil erosion and growth of vegetation. In highly sloping areas farmers will tend to adopt to various SOCETs such as grass strips in order to control water flow and consequently soil erosion.

3.3.3 Data Analysis

Data was analyzed using the Stata program where the summarize function was used to generate means, frequencies and standard deviations (table 3.1). The Probit model run in Stata provided the relationships between each SOCET and the explanatory variables. Here, the output would show the level of significance and interaction of the dependent variable i.e., the SOCET and explanatory variables and whether negative or positive. The significant variables were selected for each SOCET and the coefficient noted with its interaction.

3.3.3.1 The Probit Model

In a univariate manner this study analyzed each practice using a Probit model in Stata software. The Probit model enabled us to analyze the variables influencing the likelihood of adoption, which could have a different impact on the intensity of adoption (Sevier et al., 2004).

In this study, therefore, the number of SOCETs adopted by farmers is treated individually and a Probit model used.

The probability of a farmer adopting SOCETs is given by the expected benefits I_b^* against the expected costs of not adopting the SOCETs, I_c^*. However, I_b^* and I_c^* are latent variables. The actual adoption of SOCETs, I, I=1 if $I_c^* > I_b^*$ and I=0 if $I_c^* \leq {}_* I_b^*$. Adoption of Y_{ij} can therefore be denoted as:

$$Y_{ij} = Z\alpha - \ddot{\upsilon} \qquad (3.1)$$

Where Y_{ij} is the SOCE technology adoption dummy, Z is vector of the independent variables affecting adoption of SOCETs and respective coefficients α and $\ddot{\upsilon}$ are an error term. The general Probit model of adopting SOCETs is therefore specified as:

$$Y_{ij} = \beta_j + \beta_1 X_{ij} + \varepsilon_{ij} \qquad (3.2)$$

where Y_{ij} represents the SOCE technology adoption, *i* is the index for household, *j* represents the ward or Pastoral area, X_{ij} represents household characteristics, β_j are ward or Pastoral area fixed effects and ε_{ij} is the random error (Adusumilli & Wang, 2018).

3.4 Results and Discussion

3.4.1 Household characteristics

These include; gender of the household head, household size, occupation of the household head, education level of the household head and household years of involvement in farming. In Kenya, 24% of the households are female headed while in Ethiopia 6% are female headed. Gender affects adoption of SOCETs in that there is high adoption of manure (61%), fertilizer (98%) and intercropping (80%) in female headed households compared to SOCETs which require heavy inputs like agroforestry (57%) and grass strips (31%). The average household size in Kenya is 5 members with the majority having 3 to 8 members while in Ethiopia average household size is 7 members with majority having between 5 to 10 members. High average household size affects the adoption of SOCETs especially which require high labour like manure where 94% adoption is seen in households with large sizes and fertilizer where 98% adoption is seen in households with many members. Majority of the household's heads are not employed but work in their farm as their main source of income while the average number of years households have been involved in farming is 23 years in Kenya and 26 years in Ethiopia.

3.4.2 Biophysical factors

The biophysical factors in this study include; slope of the plot, erosion of the plot, plot soil fertility and rainfall. In Kenya, the average slope of the plot is 3.4 degrees with minimum slope being 0.1 degrees and maximum slope being 17.5 degrees while in Ethiopia, the average slope of the plot is 3.7 degrees with minimum slope being 0.11 degrees and maximum slope being 20.8 degrees. Slope influences the adoption of fertilizer, manure and grass strips as it is directly related to soil erosion and farmers will adopt lowly to fertilizer and manure as they suspect erosion will carry the inputs but adopt to grass strips to reduce erosion in high slopes. At an average slope of 3.7degrees, 95% of farmers have adopted to fertilizer while 43% have adopted manure in Ethiopia and 47% have adopted manure and 93% have adopted fertilizer at 5% slope in Kenya. 24% of the farmers in Kenya and 74% in Ethiopia perceive their plot to be susceptible to erosion while 73% of the farmers in Kenya and 91% in Ethiopia perceive that their plots to be fertile. The mean rainfall received in Kenyan sites is 1860mm with a minimum of 1686mm and a maximum of 2005mm and mean rainfall in Ethiopia is 1442mm with a minimum of 1105mm and a maximum of 1828mm.

3.4.3 Socioeconomic factors

The socioeconomic factors in this study include; tenure security, plot size, distance to plot, livestock ownership, distance to market, access to credit, group membership and access to extension. In Kenya, 50% of the households have tenure security while 86% of households in Ethiopia have tenure security or they own land title deeds. On the other hand, mean plot sizes in

Kenya are 0.75 acres while in Ethiopia is 0.6 acres while the distance to the plots in Kenya average at 5 minutes in Kenya and 17 minutes in Ethiopia. The average walking distance to market in Kenya is 111minutes and 89 minutes in Ethiopia. 98% of households in both Kenya and Ethiopia owned livestock, this was important in the adoption of manure as livestock are the main source of manure as well as in the adoption of grass strips which are used as animal feeds and crop residue management which in some cases is fed to animals. 38% of households in Kenya and 28% of households in Ethiopia had access to credit. 62% of households in Kenya and 57% of households in Ethiopia were members of farmers' groups or associations. 64% of households in Kenya and 57% of households in Ethiopia had access to extension services.

3.4.4 Extent of adoption of SOCETs

Although extensive analysis is needed, survey results showed differences and relationships in adoption across the spatial divisions. Kenya and Ethiopia extensively differ in adoption with a simple relationship being observed in technologies such as addition of fertilizer which is common in both countries. This provides an essential insight into what economic incentives are required by farmers so as to adopt multiple SOCETs. The extent of SOCETs adoption therefore, varies greatly across the two countries and across the study. Use of fertilizer is the most adopted technology having 91% of the plots in Vihiga, 97% of the plots in Kakamega, 88.87% of the plots in Angacha and 99.04% plots in Bure having fertilizer application. Other practices include; Manure with 55%, 40%, 28% and 56% of the plots in Vihiga, Kakamega, Angacha and Bure respectively having its application, intercropping with 77% and 76% of the plots in Vihiga and Kakamega respectively having the practice with crop rotation which was taken as an equivalent of intercropping in Ethiopia having being adopted in 0.09% of the plots in Angacha and 44% of the plots in Bure, Grass strips has been adopted in 32%, 39%, 33% and one percent of the plots in Vihiga, Kakamega, Angacha and Bure respectively while residue management has been adopted in 26%, 51%, 37% and 26% of the plots in Vihiga, Kakamega, Angacha and Bure respectively.

3.4.5 Probit model results on factors affecting adoption of SOCETs

Probit econometric model was run on Stata for both Kenya and Ethiopia, separately for each response variable (practices) blocking each by wards and Pastoral areas for Kenya and Ethiopia respectively. The following dependent variables were run for the Kenyan counties of Vihiga and Kakamega; Agroforestry, fertilizer, grass strips, manure, intercropping and residue management while for Ethiopia; fertilizer, grass strips, manure, crop rotation and residue management were run. Agroforestry lacked a quorum in Ethiopia to run Probit model. Factors affecting adoption of various technologies were comparatively dissimilar suggesting that the adoption of SOCETs was heterogeneous. The results are explained below;

3.4.6 Vihiga and Kakamega counties, Kenya (Appendix A)

The adoption of agroforestry in Kenya for both Vihiga and Kakamega Counties was significant in two wards; Butsotso South and Manda-Shivanga both of which are in Kakamega county. From these, the likelihood of adopt agroforestry is positively influenced by education level, and farming experience at a significance level of <0.1, rainfall at $p<0.01$and negatively influenced by soil fertility perception at $p<0.05$. This implies that farmers who have high level of education, have more farming experience and have plots in areas receiving high rainfall were more likely to adopt agroforestry. On the other hand, farmers who perceived their soil to be fertile were less likely to adopt to agroforestry. This is shown where 70% of the farmers who practiced agroforestry had acquired basic education, 100% of the farmers who practiced agroforestry had farming experience of between 10 to 50 years, and 56% of the farmers who practiced agroforestry were in areas receiving rainfall above 1850mm per annum. On the negative side, 69% of the farmers who failed to adopt to agroforestry perceived their plots to be fertile.

The adoption of fertilizer in Kenya for both Vihiga and Kakamega counties was significant in Gisambai ward which is in Vihiga county. The likelihood to adopt fertilizer was positively affected by education level of the household head and farming experience at a significance level (p) of <0.01, farmer group membership at $p<0.05$ and negatively by distance to markets at $p<0.05$ and household sizes at $p<0.01$. This means that farmers with access to education, are members of farmer groups and have many years' experience in farming are most likely to add fertilizer into their farms. On the other hand, farmers who live further from the markets and have large household sizes are less likely to adopt to fertilizer adoption. This is shown where of the farmers who used fertilizer in their plots, 84% had access to basic education and 100% of the farmers who used fertilizer had farming experience of between 10 and 55 years. On the negative side, 92% of the farmers who never used fertilizer lived more than 2 hours away from the market, 65% of those who never used fertilizer had family sizes with more than 6 members and 65% of those who never used fertilizer were members in farmer groups.

The adoption of grass strips in Kenya for both Vihiga and Kakamega Counties was significant in Kisa west and Mayoni wards which are in Kakamega county.

The likelihood to practice grass strips was positively affected by tenure security and distance to market at $p<0.01$ and group membership at $p<0.1$ while it was affected negatively by annual rainfall, education, access to credit and plot fertility at $p<0.01$ and farming experience at $p<0.05$. This means that farmers who own land, lived farther from the market and were members of farmer groups were more likely to adopt to grass strips. On the other hand, farmers who were located in areas which received high rainfall, had access to education, had high farming experience, had access to credit and perceived their soil to be fertile were less likely to adopt grass strips. This is shown where of the farmers who adopted grass strips 59% owned land or had tenure security, 76% lived 2 hours or more from the market and 93% of those who adopted were members of farmer groups. On the negative side, of the farmers who never adopted grass strips, 70% were located in areas receiving annual rainfall above 1850mm, 88% of those who never adopted had access to education, 47% had access to credit and 80 % perceived their plots to be fertile.

The adoption of manure in Kenya for both Vihiga and Kakamega Counties was significant in Kisa west, Butsotso South, Manda Shivanga and mayoni wards in Kakamega county and N.E. Bunyore, Gisambai and S. Maragoli in Vihiga county. The likelihood to use manure in Kisa West was positively influenced by tenure security at $p<0.01$ and plot fertility at $p<0.05$ while negatively by extension and plot size at $p<0.01$. In Butsotso south it was positively affected by education and household size at $p<0.05$ and farming experience at $p<0.01$while negatively by distance to market and plot fertility at $p<0.01$ and group membership at $p<0.05$. In Manda-shivanga adoption is influenced positively by farming experience at $p<0.1$ while negatively affected by household size at $p<0.01$ and plot fertility at $p<0.05$. In Mayoni, adoption is influenced positively by distance to market at $p<0.01$ and plot fertility at $p<0.05$ while its influenced negatively by distance to plots and farming experience at $p<0.01$. In North East Bunyore, adoption of manure is influenced positively by tenure security and negatively by farming experience both at $p<0.01$. In Gisambai its affected negatively by level of education at $p<0.1$. In South Maragoli, adoption of manure is influenced positively by market distance and plot size at $p<0.01$ and group membership and plot fertility at $p<0.05$ and negatively by education level at $p<0.1$, tenure security, farming experience and access to credit at $p<0.01$ and annual rainfall at $p<0.05$.

This means that in Kisa West farmer who owned land and perceived their plots to be fertile were more likely to adopt manure use while those who had access to extension and had large plot sizes were less likely to adopt manure use. This is shown where of the farmers who adopted manure, 63% owned land or had tenure security and 89% perceived their plots to be fertile while of the farmers who never adopted manure, 95% had access to extension services and76% had plot sizes greater than 0.5 ha.

In Butsotso South, farmers who had access to education, had large household sizes and had high farming experience were more likely to adopt manure while those who lived far from the market, were members of groups and perceived their plots to be fertile were less likely to adopt to manure. This is shown where of the farmers who adopted manure, 100% had access to education, 50% had household sizes more than 6 members, 100% of the farmers had farming experience of more than 10 years while of those that didn't adopt to manure 62% lived 2 hours away from the market, 66% of them were members in farmer groups and 78% ‘perceived their plots to be fertile.

In Manda-Shivanga, farmers who had high farming experience were more likely to adopt manure and those who had large household sizes and plots sizes were less likely to adopt manure. This is evident because, 100% of the farmers who adopted manure had farming experience of more than 10 years. In addition to this, of the farmers who never adopted, 71.4% had household sizes greater than 6 members and plot sizes greater than 0.5 ha.

In Mayoni, farmers that live far from the market and perceive their plots to be fertile are more likely to adopt to manure use while farmers who live far from their plots and had high farming experience are less likely to adopt to manure. This is evident because of the farmers who adopted manure, 81% lived far from the market while 100% had plot sizes greater than 0.5 ha. In addition to this, of the farmers who never adopted to manure, 84% had farming experience of more than 10 years.

In North East Bunyore, farmers who own land are more likely to adopt manure use and those who have high farming experience are less likely to adopt. This is evident because 51% of the farmers that adopted manure had tenure security. In addition, 100% of the farmers who never adopted manure had farming experience of more than 10 years.

In Gisambai, farmers who have access to education are less likely to adopt to manure. This is evident because 87.5% of the farmers who never adopted manure had access to education.

In South Maragoli, farmers who live far from the market, are members of farmers' groups, perceive their plots to be fertile and have large plot sizes are more likely to adopt to manure while those who have access to education, have tenure security, have high farming experience, are located in areas receiving high rainfall and have access to credit services are less likely to adopt to manure use. This is evident because, of the farmers who adopted to manure, 72.5% lived far from the market, 60% were in farmer groups, 75% perceived their plots to be fertile and 80% owned land greater than 0.5ha. on the other hand, 100% of the farmers who never adopted manure had access to education, 40% had tenure security, 94% had farming experience of more than 10 years, 51.5% were located in areas receiving annual rainfall which is more than 1850mm and 52% of those who never adopted to manure had access to credit.

The adoption of intercropping in Kenya for both Vihiga and Kakamega Counties was significant in Shirere ward in Kakamega county. The likelihood of farmers to adopt intercropping was influenced negatively affected by annual rainfall at a significance level less than 0.1. This means that farmers who are located in area with high rainfall are less likely to adopt intercropping. This is as shown where, out of the sampled farmers,55% never adopted to intercropping.

The adoption of residue management in Kenya for both Vihiga and Kakamega Counties was significant in Kisa west and Butsotso South wards which are in Kakamega county. The likelihood for farmers to engage in proper residue management is positively influenced by plot fertility at $p<0.05$ and negatively by group membership at $p<0.1$. This means that farmers who perceive their plots to be fertile are more likely to adopt to proper residue management while those who are members of farmer groups and associations are less likely to adopt to proper residue management. This is shown in where, of those farmers who have adopted to residue management, 88% perceive their plots to be fertile while 57% of the farmers who had not adopted residue management were members of farmers groups compared to 43% who didn't adopt and were not members of farmer groups and associations.

3.4.7 Yesir and Azuga suba watersheds, Ethiopia (Appendix B)

The adoption of manure in Ethiopia was significant at $p<0.01$ in Ambercho Wasere, Bondenna, Bucha and Gerba Findide pastoral areas in Azuga suba watershed as well as in Gulim, Jib Gedel, Tengeha and Wadra pastoral areas in Yesir/Bure watershed.

The likelihood to use manure in Ambercho Wasere was positively influenced by distance to market at $p<0.01$, education level of the household head at $p<0.1$, household size at $p<0.05$, farming experience at $p<0.01$, membership in farmer groups at $p<0.1$, soil erosion perception and annual rainfall at $p<0.01$. It is influenced negatively by extension, slope of plot and distance to the plot at $p<0.01$. This means that, farmers who lived far from the market, had access to education, had large household sizes, had high farming experience, were members of farmer groups, perceived their plots to have soil erosion and are located in areas receiving high rainfall were more likely to adopt to manure while those who had access to extension, had access to credit, plots had high slopes and lived further from their plots were less likely to adopt to manure use. This is as shown in table 3.2.

Table 3.2 Factors affecting manure adoption in Ambercho Wasere Ethiopia

Factor	**Influence**	**Evidence**
Distance to market	Positive	100% adopters lived far from the market
Farming experience	Positive	100% adopters had farming experience of over 17 years
Education	Positive	90% adopters had high education level
Farmer group membership	Positive	95% of adopters were members of farmer groups
Erosion	Positive	70% of adopters perceived erosion was a problem in their farms
Annual rainfall	Positive	100% of adopters were located in areas receiving rainfall of over 1200mm
Extension	Positive	95% of adopters had access to extension
Slope	Negative	13% of adopters lived in high slopes,
Credit	Negative	100% of adopters never had access to credit
Distance to plot	Negative	100% of adopters lived closer to their plots

In Bondenna, manure adoption was negatively influenced by slope of the plot at $p<0.05$, household size, plot fertility perception and soil erosion perception at $p<0.01$. This implies that farmers whose plots are located in sloppy areas, have large household sizes, perceive their plots to be fertile and perceive erosion to be a problem in their plots were less likely to adopt to manure use. This is as shown in table 3.3.

Table 3.3. Factors affecting manure adoption in Bondenna Ethiopia

Factor	**Influence**	**Evidence**
Slope	Negative	20% of adopters had plots with a slope of more than 2.5°
Household size	Negative	10% of adopters had household sizes of more than 6 members
Plot fertility	Negative	8% of adopters perceived their soil to be fertile
Soil erosion	Negative	82% adopters perceived erosion not to be a problem

In Bucha, manure adoption is influenced positively by annual rainfall at $p<0.01$ and negatively by household size, distance to the plot and plot fertility perception at $p<0.01$ as shown in table 3.4.

Table 3.4. Factors affecting manure adoption in Bucha Ethiopia

Factor	**Influence**	**Evidence**
Annual rainfall	Positive	100% adopters are located in areas receiving rainfall above 1120 mm
Household size	Negative	6% adopters have household sizes of more than 6 members
Distance to plot	Negative	92% adopters live less than 10 minutes away from their plots.
Plot fertility	Negative	18% adopters perceived their plots to be fertile

In Gerba Findide, manure adoption is influenced positively by household size and annual rainfall at $p<0.01$ while its influenced negatively by distance to plots and distance to market at $p<0.01$, slope of the plot at $p<0.05$, farmer group membership and farming experience at $p<0.01$ and at $p<0.05$ respectively. This is as shown in table 3.5.

Table 3.5. Factors affecting manure adoption in Gerba Findide Ethiopia

Factor	**Influence**	**Evidence**
Household size	Positive	100% adopters have household sizes of more than 6 members
Annual rainfall	Positive	74% adopters are located in areas receiving rainfall above 1215mm
Distance to plot	Negative	43% of the adopters live more than 10 minutes away from their plots.
Distance to market	Negative	47% of the adopters lived more than 60 minutes away from the market

Slope	Negative	11% of the adopters have plots with a slope of more than 2.5°
Farmer group membership	Negative	40% of the adopters were not members of farmer groups
Farming experience	Negative	7% adopters had farming experience of over 10 years

In Gulim, adoption of manure is influenced positively by tenure security, slope of the plot, household size, and annual rainfall at $p<0.01$ and access to credit at $p<0.05$ while it is negatively influenced by distance to market and plot sizes at $p<0.01$. This is as shown in table 3.6 below.

Table 3.6. Factors affecting manure adoption in Gulim, Ethiopia

Factor	Influence	Evidence
Tenure security	Positive	93% of adopters have tenure security
Slope	Positive	91% adopters have plots with a slope of more than 2.5°
Household size	Positive	93% adopters have household sizes of more than 6 members
Access to credit	Positive	53% of adopters had access to credit
Annual rainfall	Positive	100% adopters are located in areas receiving rainfall above 1215mm
Distance to market	Negative	1% adopters lived more than 60 minutes away from the market
Plot size	Negative	77% of adopters have plot sizes of less than 0.25 ha

In Jib Gedel, adoption of manure is influenced positively by tenure security, distance to plot and distance to market at $p<0.05$, extension at $p<0.01$ and livestock ownership at $p<0.01$ while it is negatively influenced by Farmer group membership, Soil erosion and plot sizes as shown in table 3.7.

Table 3.7. Factors affecting manure adoption in Jib Gedel, Ethiopia

Factor	Influence	Evidence
Tenure security	Positive	76% of adopters have tenure security
Distance to plot	Positive	72% adopters live less than 10 minutes away from their plots.
Distance to market	Positive	97% adopters lived more than 60 minutes away from the market.
Extension	Positive	77% of adopters had access to extension
Livestock ownership	Positive	98% adopters owned livestock
Farmer group membership	Negative	44% of the adopters were members of farmer groups.
Soil erosion	Negative	68% adopters perceived erosion not to be a problem
Plot size	Negative	98% of adopters have plot sizes of less than 0.25 ha

In Tengeha, adoption of manure is influenced positively by tenure security and slope of the plot at $p<0.01$, household size, membership in farmer groups and plot size at $p<0.01$ and negatively by distance to plot, distance to market, education level, farming experience, plot fertility perception, erosion perception and annual rainfall at $p<0.01$ as shown in table 3.8.

Table 3.8. Factors affecting manure adoption in Tengeha, Ethiopia

Factor	**Influence**	**Evidence**
Tenure security	Positive	75.9% of adopters have tenure security
Slope	Positive	1% adopters have plots with a slope of less than 2.5°
Household size	Positive	90% adopters have household sizes of more than 6 members
Farmer group membership	Positive	67% adopters are members of farmer groups
Plot size	Positive	75% of adopters are have plots more than 0.25 ha
Distance to plot	Negative	85% of the adopters live less than 10 minutes away from their plots.
Distance to market	Negative	35% of the adopters lived more than 60 minutes away from the market
Access to education	Negative	28% of the adopters have high level of education
Farming experience	Negative	33%of the adopters had farming experience of over 10 years
Plot fertility	Negative	3% of the adopters perceived their plots to be fertile
Soil erosion	Negative	16% of the adopters perceived erosion not to be a problem
Annual rainfall	Negative	1% of the adopters are located in areas receiving rainfall above 1215mm

In Wadra, adoption of manure is influenced positively by tenure security, market distance, access to credit, membership in farmer groups and annual rainfall at $p<0.01$ as shown in table 3.9 below.

Table 3.9. Factors affecting manure adoption in Wadra, Ethiopia

Factor	**Influence**	**Evidence**
Tenure security	Positive	78% of adopters have tenure security
Distance to market	Positive	63% adopters lived more than 60 minutes away from the market
Access to credit	Positive	73% of the adopters had access to credit
Farmer group membership	Positive	73% of the adopters were members of farmer groups
Annual rainfall	Positive	100% adopters are located in areas receiving rainfall above 1215mm

The adoption of fertilizers in Ethiopia was significant in Ambercho Wasere, Bondenna and Gerba Findide, pastoral areas of Azuga-suba watershed. The likelihood to use fertilizers in Ambercho Wasere was positively influenced by distance to plot at $p<0.05$, distance to market, plot fertility perception and soil erosion at $p<0.01$. It is influenced negatively by extension, slope of plot and annual rainfall at $p<0.01$ as shown in table 3.10.

Table 3.10. Factors affecting fertilizer adoption in Ambercho Wasere, Ethiopia

Factor	Influence	Evidence
Plot size	Positive	73% of adopters have plot sizes more than 0.25 ha
Distance to market	Positive	51% adopters lived more than 60 minutes away from the market
Plot fertility	Positive	89% adopters perceived their plots to be fertile
Soil erosion	Positive	1% of the adopters perceived erosion not to be a problem
Extension	Negative	36% of the adopters had no access to extension
Slope	Negative	1% of the adopters have plots with a slope greater than 2.5°
Annual rainfall	Negative	1% of the adopters are located in areas receiving rainfall above 1205mm

In Bondenna it was positively influenced by farming experience and negatively by distance to market at $p<0.1$, slope of the plot, annual rainfall and plot size at $p<0.01$, and erosion perception at $p<0.01$ as shown in table 3.11.

Table 3.11. Factors affecting fertilizer adoption in Bondenna, Ethiopia

Factor	Influence	Evidence
Farming experience	Positive	91% adopters had farming experience of over 10 years
Distance to market	Negative	100% adopters lived less than 60 minutes away from the market
Slope	Negative	25% of the adopters have plots with a slope greater than 2.5°
Plot size	Negative	89% of adopters have plot sizes less than 0.25 ha
Soil erosion	Negative	26% of the adopters perceived erosion not to be a problem
Annual rainfall	Negative	11% of the adopters are located in areas receiving rainfall above 1205mm

In Gerba Findide, adoption is influenced positively by distance to market at $p<0.01$ and plot fertility at $p<0.1$ perception while its influenced negatively by slope of the plot at $p<0.01$ and household size at $p<0.01$ as shown in table 3.12 below.

Table 3.12. Factors affecting fertilizer adoption in Gerba Findide, Ethiopia

Factor	Influence	Evidence
Distance to market	Positive	89% adopters lived less than 60 minutes away from the market
Plot fertility	Positive	97% adopters perceived their plots to be fertile
Slope	Negative	2% of the adopters have plots with a slope greater than 2.5°
Household size	Negative	1% of the adopters have household sizes of more than 6 members

The adoption of grass strips in Ethiopia was significant in Ambercho Wasere, Bondenna, Bucha and Gerba Findide pastoral areas in Azuga-suba watershed as well as in Gulim in Yesir/Bure watershed. The likelihood to use grass strips in Ambercho Wasere was positively influenced by tenure security, distance to plot, membership in farmer groups and plot fertility perception at $p<0.01$ and distance to market at $p<0.1$. It is influenced negatively by extension, household size, farming experience, slope of plot, credit, and annual rainfall at $p<0.01$ and by erosion perception at $p<0.1$ as shown in table 3.13 below.

Table 3.13. Factors affecting grass strips adoption in Ambercho Wasere, Ethiopia

Factor	Influence	Evidence
Tenure security	Positive	98% of adopters have tenure security
Distance to plot	Positive	1% of the adopters live less than 30 minutes away from their plots.
Distance to market	Positive	33% of the adopters lived less than 60 minutes away from the market
Plot fertility	Positive	81% of the adopters perceived their plots to be fertile
Farmer group membership	Positive	75% of the adopters aren't members of farmer groups
Extension	Negative	32% of adopters had access to extension, 67.9% hadn't
Slope	Negative	6% of the adopters have plots with a slope of more than 2.5°
Household size	Negative	11% of the adopters have household sizes of more than 6 members
Farming experience	Negative	21% of the adopters had farming experience of over 10 years
Access to credit	Negative	25% of the adopters never had access to credit
Soil erosion	Negative	68% adopters perceived erosion not to be a problem
Annual rainfall	Negative	8% adopters are located in areas receiving rainfall above 1215mm

In Bondenna it was positively influenced by soil erosion perception and annual rainfall at $p<0.1$ while it was negatively influenced by size of the plot at $p<0.01$ as shown in table 3.14 below.

Table 3.14. Factors affecting grass strips adoption in Bondenna, Ethiopia

Factor	Influence	Evidence

Soil erosion	Positive	74% of the adopters perceived erosion to be a problem
Annual rainfall	Positive	19% adopters are located in areas receiving rainfall above 1200mm
Plot size	Negative	73% of adopters have plot sizes less than 0.25 ha

In Bucha adoption is influenced positively by soil erosion perception at $p<0.01$ and negatively by plot size and annual rainfall at $p<0.01$ as shown in table 15 below.

Table 3.15. Factors affecting grass strips adoption in Bucha, Ethiopia

Factor	**Influence**	**Evidence**
Soil erosion	Positive	55% of the adopters perceived erosion to be a problem
Plot size	Negative	73% of adopters have plot sizes less than 0.25 ha

In Gerba Findide, adoption is influenced positively by slope of the plot at $p<0.1$ access to extension and access to credit at $p<0.01$ while its influenced negatively by distance to market at $p<0.1$, household size, farmer group membership and annual rainfall at $p<0.01$ as shown in table 3.16 below.

Table 3.16. Factors affecting grass strips adoption in Gerba Findide, Ethiopia

Factor	**Influence**	**Evidence**
Slope	Positive	89% of the adopters have plots with a slope of more than 2.5°
Extension	Positive	68% of the adopters had access to extension
Access to credit	Positive	79% of the adopters never had access to credit
Distance to market	Negative	86% of the adopters lived more than 60 minutes away from the market
Farmer group membership	Negative	73% adopters aren’t members of farmer groups
Household size	Negative	74% of the adopters have household sizes of more than 6 members
Annual rainfall	Negative	1% of the adopters are located in areas receiving rainfall above 1215mm

In Gulim, adoption is influenced positively by level of education of the household head and household size at $p<0.01$ while it is negatively influenced by distance to market and distance to plot at $p<0.01$ and annual rainfall at $p<0.1$ as shown in table 3.17 below.

Table 3.17. Factors affecting grass strips adoption in Gulim, Ethiopia

Factor	**Influence**	**Evidence**
Education	Positive	100% adopters had high education level

Household size	Positive	100% adopters have household sizes of more than 6 members
Distance to plot	Negative	100% of adopters live less than 30 minutes away from their plots.
Distance to market	Negative	2% of the adopters lived more than 60 minutes away from the market
Annual rainfall	Negative	34% of the adopters are located in areas receiving rainfall less than 1570mm

The adoption of crop rotation in Ethiopia was significant in Gulim, Jib Gedel, Tengeha and Wadra pastoral areas in Yesir/Bure watershed. The likelihood to adopt crop rotation in Gulim was influenced positively by distance to market, slope of the plot, household size, farming experience and access to credit at $p<0.01$ and soil fertility perception at $p<0.05$ and negatively by tenure security annual rainfall and plot size at $p<0.05$. This is shown in table 3.18 below.

Table 3.18. Factors affecting crop rotation adoption in Gulim, Ethiopia

Factor	**Influence**	**Evidence**
Distance to market	Positive	100% adopters lived more than 60 minutes away from the market
Slope	Positive	97% adopters have plots with a slope of more than 2.5°
Household size	Positive	60% adopters have household sizes of more than 6 members
Farming experience	Positive	14% of the adopters had farming experience of over 10 years
Access to credit	Positive	55% of adopters had access to credit
Plot fertility	Positive	99% adopters perceived their plots to be fertile
Tenure security	Negative	16% of the adopters had tenure security
Plot size	Negative	13% of the adopters have plot sizes greater than 0.25 ha
Annual rainfall	Negative	74% adopters are located in areas receiving rainfall less than 1570mm

In Jib-Gedel, adoption of crop rotation is influenced positively by distance to plot and household size at $p<0.1$ and annual rainfall at $p<0.01$ while its influenced negatively by tenure security at $p<0.05$, distance to market at $p<0.01$, plot slope at $p<0.01$, access to extension at $p<0.1$, plot size at $p<0.01$, farming experience at $p<0.05$ and plot fertility perception at $p<0.05$ as shown in table 3.19 below.

Table 3.19. Factors affecting crop rotation adoption in Jib Gedel, Ethiopia

Factor	**Influence**	**Evidence**
Distance to plot	Positive	100% of the adopters live far than 30 minutes away from their plots.
Household size	Positive	60% adopters have household sizes of more than 6 members

Annual rainfall	Positive	100% adopters are located in areas receiving rainfall above 1570mm
Distance to market	Negative	95% of the adopters lived less than 60 minutes away from the market
Plot size	Negative	68% of the adopters have plot sizes less than 0.25 ha
Plot fertility	Negative	87% of the adopters perceived their plots to be infertile
Extension	Negative	30% of the adopters had access to extension
Slope	Negative	1% of the adopters have plots with a slope of more than 2.5°
Tenure security	Negative	29% of the adopters have tenure security
Farming experience	Negative	5% of the adopters had farming experience of over 10 years

In Tengeha, adoption of crop rotation is influenced positively by household size at $p<0.1$, farmer group membership and soil erosion perception at $p<0.01$ and annual rainfall at $p<0.05$ while its influenced negatively by distance to market at $p<0.1$, access to extension at $p<0.01$ and soil fertility perception at $p<0.05$ as in table 3.20 below.

Table 3.20. Factors affecting crop rotation adoption in Tengeha, Ethiopia

Factor	**Influence**	**Evidence**
Household size	Positive	80% adopters have household sizes of more than 6 members
Farmer group membership	Positive	61% adopters are members of farmer groups
Soil erosion	Positive	90% of the adopters perceived erosion not to be a problem
Annual rainfall	Positive	100% adopters are located in areas receiving rainfall more than 1570mm
Distance to market	Negative	1% of the adopters lived more than 60 minutes away from the market
Extension	Negative	8% of the adopters had access to extension
Plot fertility	Negative	96% of the adopters perceived their plots to be infertile

In Wadra, adoption of crop rotation is influenced positively by tenure security and plot slope at $p<0.01$, and access to credit at $p<0.1$ while it is influenced negatively by distance to plot and market distance at $p<0.01$, plot size and household size at $p<0.05$ and farming experience at $p<0.01$ as shown in table 3.21.

Table 3.21. Factors affecting crop rotation adoption in Wadra, Ethiopia

Factor	**Influence**	**Evidence**
Tenure security	Positive	79% of adopters have tenure security
Slope	Positive	82% of the adopters have plots with a slope of more than 2.5°
Access to credit	Positive	75% of the adopters had access to credit

Distance to plot	Negative	6% of the adopters live less than 30 minutes away from their plots.
Distance to market	Negative	92% adopters lived less than 60 minutes away from the market
Plot size	Negative	100% of adopters have plot sizes less than 0.25 ha
Household size	Negative	85% adopters have household sizes of less than 6 members
Farming experience	Negative	5% of the adopters had farming experience of over 10 years

The adoption of proper residue management in Ethiopia was significant in Ambercho Wasere, Bondenna, Bucha and Gerba Findide pastoral areas in Azuga-suba watershed as well as in Gulim, Jib-Gedel, Tengeha and Wadra pastoral areas in Yesir/Bure watershed. The likelihood to adopt proper residue management in Ambercho Wasere was positively influenced by distance to plot, plot fertility perception and soil erosion perception at $p<0.05$ and plot size and household size at $p<0.01$. It is influenced negatively by distance to market at $p<0.1$ and farmer group membership at $p<0.01$. This is shown on table 3.22.

Table 3.22. Factors affecting proper residue management adoption in Ambercho Wasere, Ethiopia

Factor	**Influence**	**Evidence**
Distance to plot	Positive	2% of the adopters live less than 30 minutes away from their plots.
Plot size	Positive	100% of adopters have plot sizes greater than 1 ha
Household size	Positive	77% adopters have household sizes of more than 6 members
Plot fertility	Positive	95% adopters perceived their plots to be fertile
Soil erosion	Positive	21% of the adopters perceived erosion to be a problem
Distance to market	Negative	66% adopters lived less than 60 minutes away from the market
Farmer group membership	Negative	98% adopters are not members of farmer groups

In Bondenna residue management adoption was negatively influenced by tenure security at $p<0.05$, distance to market and farmer group memberships at $p<0.1$, soil erosion perception, household size, plot size and slope of the plot at $p<0.01$ as shown in table 3.23 below.

Table 3.23. Factors affecting proper residue management adoption in Bondenna, Ethiopia

Factor	**Influence**	**Evidence**
Tenure security	Positive	98% of adopters lacked tenure security
Distance to market	Negative	85% adopters lived less than 60 minutes away from the market
Slope	Negative	29% of the adopters have plots with a slope of more than 2.5°

Household size	Negative	88% adopters have household sizes of more than 6 members
Plot size	Negative	78% of the adopters have plot sizes greater than 0.25 ha
Farmer group membership	Negative	2% of the adopters are not members of farmer groups

In Bucha adoption is influenced positively by tenure security, distance to plot and soil erosion perception at $p<0.01$ while negatively by distance to the market and annual rainfall at $p<0.01$, level of education and plot size at $p<0.05$ and as shown in table 3.24.

Table 3.24. Factors affecting proper residue management adoption in Bucha, Ethiopia

Factor	**Influence**	**Evidence**
Tenure security	Positive	97% of adopters have tenure security
Distance to plot	Positive	100% of non-adopters live less than 30 minutes away from their plots.
Soil erosion	Positive	55% adopters perceived erosion to be a problem
Distance to market	Negative	74% of adopters lived less than 60 minutes away from the market
Education	Negative	38% adopters had high education level
Plot size	Negative	99% of adopters have plot sizes greater than 0.25 ha
Annual rainfall	Negative	100% adopters are located in areas receiving rainfall more than 1570mm

In Gerba Findide, adoption is influenced positively by annual rainfall at $p<0.05$, education level, plot size and farming experience at $p<0.01$ while its influenced negatively by access to extension, household size and access to credit at $p<0.01$ and farmer group membership at $p<0.05$ as shown in table 3.25 below.

Table 3.25. Factors affecting proper residue management adoption in Gerba Findide, Ethiopia

Factor	**Influence**	**Evidence**
Education	Positive	41% adopters had high education level
Plot size	Positive	99% of adopters have plot sizes greater than 0.25 ha
Farming experience	Positive	95% adopters had farming experience of over 10 years
Annual rainfall	Positive	69.5% adopters are located in areas receiving rainfall more than 1570mm
Extension	Negative	33% of adopters had access to extension
Household size	Negative	7% of the adopters have household sizes of more than 6 members
Access to credit	Negative	94% of adopters had no access to credit
Farmer group membership	Negative	91% adopters are not members of farmer groups

In Gulim, adoption of residue management is influenced positively by distance to plot and slope of the plot at $p<0.05$, level of education, plot size and farmer group membership at $p<0.01$ and negatively by distance to market at $p<0.05$, farming experience, access to credit and annual rainfall at $p<0.01$. This is shown in table 26 below.

Table 3.26. Factors affecting proper residue management adoption in Gulim, Ethiopia

Factor	Influence	Evidence
Distance to plot	Positive	70% of adopters live more than 30 minutes away from their plots.
Slope	Positive	96% adopters have plots with a slope greater than 2.5°
Education	Positive	71% adopters had high education level
Plot size	Positive	100% of adopters have plot sizes greater than 0.25 ha
Farmer group membership	Positive	97% adopters are members of farmer groups
Distance to market	Negative	67% of adopters lived less than 60 minutes away from the market
Farming experience	Negative	47% adopters had farming experience of over 10 years
Access to credit	Negative	42% of adopters had access to credit
Annual rainfall	Negative	44% adopters are located in areas receiving rainfall more than 1570mm

In Jib-Gedel, adoption of residue management is influenced positively by market distance and plot slope at $p<0.05$ and farmer group membership at $p<0.01$ while its influenced negatively by distance to plot and plot size at $p<0.05$, soil erosion perception at $p<0.01$ and annual rainfall at $p<0.1$ as shown in table 3.27 below.

Table 3.27. Factors affecting proper residue management adoption in Jib-Gedel, Ethiopia

Factor	Influence	Evidence
Distance to market	Positive	77% of adopters lived more than 60 minutes away from the market
Slope	Positive	77% adopters have plots with a slope of more than 2.5°
Farmer group membership	Positive	63% adopters are members of farmer groups
Distance to plot	Negative	100% of adopters live less than 30 minutes away from their plots.
Plot size	Negative	78% of adopters have plot sizes less than 0.25 ha
Soil erosion	Negative	17% adopters perceived erosion to be a problem
Annual rainfall	Negative	100% adopters are located in areas receiving rainfall more than 1570mm

In Tengeha, adoption of residue management is influenced positively by household size and farmer group membership at p<0.01while it influenced negatively by access to credit services at p<0.05 as shown in table 3.28 below.

Table 3.28. Factors affecting proper residue management adoption in Tengeha, Ethiopia

Factor	Influence	Evidence
Positive	Positive	87% adopters have household sizes of more than 6 members
Farmer group membership	Positive	90% adopters are members of farmer groups
Access to credit	Negative	59% of adopters had no access to credit

In Wadra, adoption of *residue management* is influenced negatively by distance to plot, market distance and plot size at p<0.05 and farmer groups membership at p<0.01 as shown in table 3.29 below.

Table 3.29. Factors affecting proper residue management adoption in Bucha, Ethiopia

Factor	Influence	Evidence
Distance to plot	Negative	89% of adopters live less than 30 minutes away from their plots.
Distance to market	Negative	27% of the adopters lived more than 60 minutes away from the market
Plot size	Negative	2% of the adopters have plot sizes less than 0.25 ha
Farmer group membership	Negative	77% adopters are not members of farmer groups

3.4.8 Constraints to the adoption of sustainable land management technologies

3.4.8.1 Agroforestry

The constraints to agroforestry adoption in Kenya counties of Vihiga and Kakamega includes education level of the households' heads, farming experience, high annual rainfall and farmers' perceptions that the soils are fertile. Soil fertility perception is largely determined by the observed yields (Marenya et al., 2008) after a harvest where a farmer decides whether the soil is fertile or not, depending on the amount of yield they obtained. The finding that lack of education constrains the adoption of agroforestry is in agreement with Binam et al. (2017) findings who noted that education as a proxy for access to information affects the knowhow of farmers and improves decision making skills (Mwase et al., 2015). With high rainfall farmers tend to edge out agroforestry so as to increase production with the perception that the benefits associated with agroforestry such as shading, environmental conservation (Smith, 2010) and forages for animals are not required. On the other hand, in Ethiopia, Madalcho & Tefera (2016) found out that education level of the household head, plot size, farming experience, tenure security and income increased the tendency of the farmers to adopt to agroforestry.

3.4.8.2 Fertilizer

The constraints to adoption of fertilizer use in Kenya counties of Vihiga and Kakamega include, distance to urban market, education level of the households' heads, farming experience, household size and farmers' non-membership in groups and associations. In the Ethiopian watersheds of Yesir and Azuga suba, constraints include, farmers' perceptions of soil fertility, education level of the households' heads, soil erosion perception, farming experience, access to extension, slope of the plot, annual rainfall, distance to markets, plot size and household size.

Access to basic education is considered a proxy for farmers to having access to technical knowledge on the use of fertilizers, and therefore, lack of access to education constrains adoption of fertilizers (Waithaka et al., 2007). Education presumably influences a better understanding of the different types of fertilizers, requirements on specific crops, soil types and application timing (Omamo et al. 2002). Extension services raise farmers' understanding of the benefits of fertilizers (Eba & Bashargo 2014). This increases adoption to fertilizer use. According to Waithaka et al. (2007), longer distances to urban markets increase the overall fertilizer costs as well as the time needed to reach them discouraging their use. This is due to increased transportation costs (Gebresilassie and Bekele, 2015). For most smallholder farmers in Africa, purchasing power is low and therefore with increasing plot size decreases the ability to afford the amount of fertilizer required. Farming experience is known to improve farmers' skills on the use of fertilizers (Eba & Bashargo 2014) encouraging adoption. Lack of experience is a constraint to adoption. Rain-fed agriculture is mainly associated with risks of low rain (Tsehaye, 2008), this constrains the adoption to the use of fertilizer as farmers' fear making losses. Where farmers have relatively fertile farms, they tend to be reluctant in adding fertilizers (Tsehaye, 2008; Onyenweaku et al., 2007). According to Tchale et al. (2004), large household sizes results into more mouths to feed leading to households suffering from chronic food shortages. These households therefore, lack financial resources to purchase fertilizers as their money is used to purchase food. Farmer groups membership exposes farmers to a wide range of research information and allows individuals to learn and share information on agricultural inputs and marketing (Odendo et al., 2011). This encourages adoption. Failure for farmers to be involved in these groups leaves them with no knowledge and hence less adoption. Highly sloping plots are more susceptible to soil erosion resulting to smaller yields as compared to flat land (Aemro and Musa, 2016). Farmers therefore, prefer investing on flatter plots than sloppier plots since they provide higher yields. Farmers therefore, do not apply fertilizers on sloppy plots due to the fear that it will be eroded leading to losses.

3.4.8.3 Grass strips

The constraints to adoption of grass strips in Kenya counties of Vihiga and Kakamega include, tenure security, distance to market, farming experience, household sizes, membership in farmer groups or associations, annual rainfall, education level of the households' heads, access to credit and farmers' perceptions on soil fertility. In the Ethiopian watersheds of Yesir and Azuga suba, the constraints include, tenure security, distance to plot, distance to market, farmers' perception on soil fertility, membership in farmer groups or associations, soil erosion perception, annual rainfall, slope of the plot, plot size, household size, farming experience, access to credit and extension services.

Lack of tenure security hinders adoption of grass strips as there is no formal responsibility bestowed upon the caretaker of the land by the owner (Mugure et al., 2013). Farmers in this case do not want to engage in long term technologies which may not be beneficial to them. Basic education ensures that farmers have more access to information related to grass strips benefits and can easily adopt it (Tenge et al., 2004). On the other hand, access to education offers farmers other alternative technologies which they may perceive more profitable than grass strips (Shiferaw et al., 2009). According to Tenge et al., (2004) and Semgalawe (1998), farmers who perceive their soils to be fertile do not adopt to grass strips or any other soil and water conservation practice. Small plot sizes discourage adoption of grass strips as farmers have no room for grasses but for growing their food crops (Irungu, 1998). Farmers with plots lying in high slopes tend to adopt to grass strips to reduce soil erosion while those on the low-lying areas do not take erosion seriously as it is not very much prevalent (Tenge et al., 2004). Access to credit improves farmers' ability to purchase cultivars and in some cases livestock which is the main factor encouraging adoption of grass strips (Kammer, 2014). The large the household, the more demand for food requiring the household to use every part of their farmland for food production (Sood, 2006; Clay, Reardon, & Kangasniemi, 2015). A long distance to plots means that one has to travel for long distances to get the grass where the adoption motivation is livestock and, in some cases, transporting planting materials and inputs is a constraint (Pachepsky et al., 1996). This affects adoption. Some farmer groups or associations encourage farmers to plant other types of fodder crops for their livestock such as the protein rich Calliandra (Franzel et al., 2014) edging out grass. This has a significant effect in adoption constraining it. According to the International institute of rural reconstruction (IIRR) (1995), grass strips are not applicable on steep slopes or areas with long duration rainfall. This means that farmers will not find any use for the grass strips in these areas and therefore will not adopt it. Access to extension services increases the awareness of farmers to the importance of grass strips especially in the control of erosion (Kammer, 2014; Eba & Bashargo 2014).

3.4.8.4 Manure

The constraints to adoption of manure use in Kenya counties of Vihiga and Kakamega include, tenure security, farmers' perception of soil fertility, access to extension and credit services, plot size, distance to market, membership in farmer groups or associations, farming experience, Distance to plot, annual rainfall, household size and level of education of household head. The constraints to manure use in the Ethiopian watersheds of Yesir and Azuga suba include, distance to market, level of education of household head, household size, farming experience, access to extension, access to credit services, membership in farmer groups or associations, soil erosion perception, annual rainfall, slope of the plot and distance to the plot.

Access to basic education ensures that farmers have more access to information related to the use of manure and its benefits and therefore empowers them to adopt (Mustafa-Msukwa et al., 2011). Reduction in the use of manure is due to the fact that learned farmers have the knowledge of using both manure and fertilizer together to increase production (Mustafa-Msukwa et al., 2011). Closeness to urban markets ensures that farmers can easily access inorganic fertilizers and therefore leads to limited use of manure (Mwangi, 1996). It is expected that the more a farmer has experience in farming, the more they are likely to adopt to manure use (Liu et al., 2017). Lack of experience in farming limits adoption of manure use. Being members of farmer groups and associations leads to improved knowledge of the farmers to manure increasing adoption (Mwangi, 1996). Lack of farmers' involvement in groups and associations leads to low adoption of fertilizers. Tenure security inspire farmers to protect the nature of their farms through permanent land management systems for example addition of manure (Kassie, 2016). Lack of tenure security of farmers hinders addition of manure as the farmers tend to feel as it is wasting their resources on someone else farm. Large households in most cases provide farmers with more dependable access for inexpensive labor (Kammer, 2014) encouraging manure adoption. Large sized plots and plots located far from the farmers' homes are labour intensive when it comes to transportation and the addition of manure which in itself is bulky (Waithaka et al., 2007; Giller et al., 2006). This discourages the application of manure in plots with these characteristics. Extension enhances the importance and benefits of manure use improving adoption. Lack of extension hinders adoption (De Groote et al., 2001). Plots susceptible to soil erosion discourages addition of manure due to the risk of losing the resource to runoff (Larney and Janzen, 1996). Where farmers have relatively fertile farms, they tend to be reluctant in adding manure transferring it to the unfertile plots. High annual rainfall is associated with erosion constraining farmers from adoption to manure use (Larney and Janzen, 1996) while low annual rainfall constrains the adoption of manure. This is because low rainfall especially at the start of the season tends to cause the manure to scorch the crops (Paulus, 2015). Plots in areas with low lying slopes tends to have low erosion and, in most cases, fertile compared to plots on sloppy grounds. This influences farmers' adoption to manure as they prefer adding manure to plots which have low fertility. Credit improves the ability of farmers to purchase inputs as well as pay for labour (Gachene and Wortmann, 2007). Access to credit inhibition of adoption to manure can be explained by the increased ability of farmers to buy inorganic fertilizers. On the other hand, lack of access to credit inhibits adoption of manure could be due to the inability of the farmer to pay for labour services (Kenea et al., 2000; Tsehaye, 2008).

3.4.8.5 Intercropping and crop rotation

Adoption to intercropping in Kenya counties of Vihiga and Kakamega was constrained by annual rainfall. The constraints to crop rotation in the Ethiopian watersheds of Yesir and Azuga suba include, distance to market, Tenure security, household size, farming experience, farmers' perception of soil fertility, access to extension, access to credit services, annual rainfall and plot size.

Areas receiving high rainfall throughout the year are attributed to high production (Soini, 2007). Therefore, farmers do not find the importance of adopting intercropping to improve their yields (Ketema & Bauer, 2012). This constraint the adoption of intercropping. Farming experience facilitates the adoption of intercropping and crop rotation by improving the knowledge and awareness on the benefits of the technologies (Kelsey, 2013). Crop rotation is less applicable for long term crops discouraging short term tenure (IIRR, 1995). This discourages adoption when the farmer involved lacks tenure security of their farm. In areas with seasonal migrations, crop rotation is known to have a high labour demand problem (IIRR, 1995). This is a benefit to households with many members but a constraint to less membership household sizes. Closeness to markets entails farmers access to inputs especially seeds which they have given priority as well as the required nutrient supplements, far distance to markets therefore discourages adoption to crop rotation. The finding that farmer's perception that their plots are fertile constraints adoption of crop rotation is in line with Odendo et al. (2011) who concluded that perception that the plot is infertile will encourage farmers to adopt crop rotation to solve the problem. Farmers' access to credit services improves their purchasing power of seedlings and inputs encouraging adoption of crop rotation (Kenea et al., 2000). The finding that larger plot sizes discourages adoption is in line with Ketema & Bauer, (2012) who found out that increasing the land size decreases the probability of adoption as it increases input costs.

3.4.8.6 Residue management

The constraints to adoption of residue management in Kenya counties of Vihiga and Kakamega include, farmers' perception of soil fertility and membership in farmer groups or associations. In the Ethiopian watersheds of Yesir and Azuga suba, the constraints to adoption of residue management are, distance to the plot, plot size, household size, farmers' perception of soil fertility, soil erosion perception, Tenure security, slope of the plot, level of education of household head, membership in farmer groups or associations and access to extension. This study shows that when soils are fertile, and farmers are members in groups or associations they are less likely to adopt residue management in Kenya. In Ethiopia the study shows that when the plots are close to home, the plots are large, the households have many members, farmers perceive their plots to be fertile, have high slopes and are perceptible to erosion, farmers lack tenure security, have high level of education, are members of farmer groups and have access to extension are less likely to adopt to residue management.

Larger households likely provide farmers with more dependable access for inexpensive labor (Kammer, 2014) but also many mouths to feed. This brings about a requirement to use every piece of biomass to bring food to the table including selling residues for fodder (Tittonell et al., 2009). Extension enhances farmers' knowledge and understanding of residue management therefore increasing adoption. Extension also increases the knowledge of other land management options such as manure which encourages feeding of residues to livestock in bid to increase manure production. Lack of access to credit leads to poor purchasing power of farm inputs, animal feeds and other commodities such as fuel and building materials leading to farmers substituting these inputs with residues (Jassogne et al., 2013). According to IIRR, (1995), residues are difficult to spread on highly sloping slopes and in some cases getting washed away by water discouraging adoption. Small sized plots due to continuous divisions exacerbates land tenure problems (Mugure et al., 2013) discouraging residue management. Long distances to plots discourage transfer of residues for other uses compared to plots which are closer to home (Kelsey, 2013). Having plots close to home constraints adoption. Farmers perception that their plots are fertile constraints adoption of use of residues for fertility improvement discouraging adoption (Odendo et al. 2011). Farmers' involvement in groups or associations are more likely to adopt to residue management (Liu et al., 2018). This is because in groups, farmers are able to share experiences and knowledge encouraging adoption. It is also in these groups that they obtain the knowledge of other technologies such as composting which encourage the use of residues to make compost manure. Lack of tenure security discourages residue management as farmers want to carry every part of the crop away from the rented land to attain maximum benefits.

3.5 Conclusion and recommendations

The results demonstrate that the extent of adoption of SOCETs are influenced by several variables such as group membership to local institutions, credit constraints, head access to basic education, livestock ownership, distance to urban markets, rainfall, plot slope farming experience, soil erosion, soil fertility, plot sizes, household size, tenure security among others. The significant importance of constraints relating to social capital (such as membership in farmer groups and associations, credit, household head education, livestock ownership, distance to markets, rainfall, plot slope and sizes, household sizes, extension etc.) on the adoption of SOCETs suggests that there is a need for establishing and strengthening local institutions and service provision to accelerate and sustain SOCETs adoption.

Local organizations assume critical roles of enriching farmers with timely information, providing inputs (e.g. labour, credit, insurance) and technical assistance. The significance of accessing credit is tied to its influence in the ability of purchasing inputs (improved seed and fertilizer) while being a member of farmer groups or associations ensures that a farmer is able or may get subsidized or free inputs from the agricultural institutions. Livestock ownership ensures that farmers have some manure by the start of a season therefore, ensuring every farmer owns at least one or two improved breeds and improved forage legumes would ensure that there is increase in products sourced from livestock including manure. Rainfall effects on adoption of SOCETs are centered on slope and erosion for areas receiving high rainfall. Rainfall disturbance in addition to inorganic fertilizer results from scorching of plant roots due to inadequate rainfall resulting to less water to dissolve the chemicals. Rainfall forecasting is important in ensuring proper timing and distribution. In addition to this, the use of SOCETs is associated positively with the farmer's access to extension, education and involvement in associations. This is because these are associated with personal development by providing information to the farmers. This proposes that an investment in a proper and working extension service provision, farmers training centers and formation of farmer groups with linkages to the government and non-governmental institutions can establish a positive effect on the adoption of SOCETs. Investment in rural state-funded education will encourage the adoption of SOCETs and practices.

CHAPTER FOUR

Spatial distribution of factors affecting adoption of soil organic carbon enhancements technologies among small scale farmers in Kenya and Ethiopia.

4.1 Abstract

Soil degradation has been of great concern in the Sub-Saharan Africa (SSA) where it causes a decline in Soil Organic Carbon (SOC), the basis of soil fertility. Loss of SOC leads to low agricultural production. However, the decrease in SOC can be reversed by adopting soil organic carbon enhancing technologies (SOCETs) that encourage accumulation of residues in the soil. Nevertheless, despite the benefits associated with the adoption of SOCETs and the efforts being carried out by various non-governmental and governmental organizations, the adoption of SOCETs has remained low. This study utilizes spatial and socio-economic data on issues associated with the adoption of SOCETs obtained via households' surveys in two counties in western Kenya (Kakamega and Vihiga counties) and two watersheds in Ethiopia (Yesir and Azuga-suba watersheds) to examine what drives the adoption of SOCETs across space. This analysis was done using two models; random forest (RF) and geographically weighted regression (GWR). RF was used to predict adoption of each SOCET across space with SOCET adoption being the dependent variable and the driving factors of the adoption to each SOCET – as obtained by running a Probit model and as Geographic Information System (GIS) rasters – being the explanatory variables. GWR was used to predict the effect of each driving factor on the adoption of SOCETs as predicted on RF. The results show that, the influence of the factors affecting the adoption of SOCETs vary greatly across space with adoption being affected either positively or negatively across the study areas and with a varying magnitude. This means that driving factors could encourage adoption of SOCETs in one geographical location while at the same time discourage adoption on another and at different magnitudes across these locations. The varying distribution of adoption of SOCETs based on the varying effects of driving factors across the geographical space is of great importance in determining the approach in which governmental and non-governmental organizations adopt in upscaling the adoption of SOCETs among small-scale farmers. While carrying out similar studies, researchers are encouraged to adopt a spatial methodology so as not to miss this important variation of geographical space.

Keywords: Technologies, Soil organic carbon, Small scale farmers, Spatial distribution, Random forest, Geographic weighted regression

4.2 Introduction

Soil organic carbon (SOC) is reported to increase soil fertility and overall land productivity (Lal et al., 1997). Changes in land use and management have had a prevailing effect on SOC, increasing or decreasing it depending on whether residue is added or removed from the land (Don et al., 2011). However, boosting agricultural management through employing land management practices that encourage residue accumulation leads to increased carbon dioxide sequestration thus increasing SOC (Rees et al., 2005; Neill, 2011). These land management (LM) practices include but not limited to agroforestry, intercropping and crop rotation, minimum tillage, cover cropping, addition of manure, addition of fertilizer in the recommended amounts, mulching, planting of grass strips, proper residue management, among others. (Wezel et al., 2014). Adoption of these LM practices stands out to be very crucial in increasing agricultural production and therefore ensuring food security and improving the livelihoods of many small-scale farmers in many parts of the world (Kassie et al., 2009).

In a study carried out in Ethiopia, Wolayita zone of the SSNPR region, Toma et al., (2017) found that factors such as education level of the household head, perception of land degradation problems, land tenure certification, access to credit, access to extension through the development agents, membership in the community organizations, participation in government awareness programme and livestock ownership positively affected adoption of LM practices while distance to market, labour availability negatively affected adoption. Another study carried out in Oromia region of Ethiopia by Seguye, (2017), indicated that education level of the household head, farm size, perception of land degradation, perception of effectiveness of LM practices, access to extension and livestock ownership positively affected the adoption of LM practices while distance to market affected the adoption of LM practices negatively. A study carried out in Namibia by Nena, (2015) investigated the constraints to adoption of LM technologies. The most common constraints to adoption of LM technologies found were, climatic characteristics especially low and unpredictable rainfall, limited farm size, lack of extension services and institutional support, shortage of labour and lack of finances and other resources. In Kenya, Kakamega County, Kinyangi, (2014) found out that access to credit, extension services, distance to market, level of education of household head, age and gender of the household head affected adoption positively while in Machakos County, Mutuku, (2017) found out that household head age and gender, group membership, access to agricultural extension services and inaccessible credit affected adoption positively while cost of inputs, access to information, cost of labor, access to appropriate farm machines, input-output markets and farmer' perception of the reliability of the practice affected adoption of LM practices negatively. According to Fazio et al., (2019), there are a wide variety of factors that encourage or discourage farmers to adopt LM practices to enhance SOC. These factors include personal characteristics, government agricultural policies, economic factors, access to education and information, geographical factors, land tenure, and community related factors. Out of these factors are barriers and motivators to farmers' adoption of LM practices which rely on the type of LM practice adopted (Fazio et al., 2019).

Barriers are categorized into: Economic, Education and Information barriers, Resistance to change, Barriers Related to LM Technologies, Social Context, Financial and Material Infrastructure, Land Tenure Constraints, Personal characteristics. Economic barriers refer to costs that is, financial ability, cost of change, risks and uncertainties, incentives and low output commodity prices and the time taken to achieve benefits (Long et al., 2016). Education and Information barriers refer to barriers associated with lack of institutional support, lack of information and proper management of the information (Rodriguez et al., 2009). Barriers associated with resistance to change is farmers' hesitancy to uptake new land management technology (Rodriguez et al., 2009). Barriers related to LM technologies result where the technology is time consuming and this discourages farmers from adopting, where it results to more labour requirement than is available, where they lack demonstrations for farmers who want to see the activity before they decide to implement, technology incompatibility with farm size as some farms have reduced due to subdivision (Mitchel et al., 2007. Barriers related to social context include social norms and beliefs, peer pressure, lack of role models, and misleading perceptions about LM technologies (Fleming & Vanclay, 2010). Financial and Material Infrastructure related barriers include, inputs and equipment sources, financial institutions, market and lack of processing options for small-scale producers (Rodriguez et al., 2009). Land Tenure Constraints related barriers are associated with farming leased land in which farmers might refrain from adopting LM technologies because they may not enjoy long term benefits (Banadda, 2010). Personal characteristics barriers include, age, farming experience, farmer perceptions and external support from government, NGO's and community groups (Dunn et al., 2000).

Various studies have been conducted to analyze factors influencing the adoption of soil organic carbon enhancement technologies (SOCETs) and those that influence decision-making of farmers to adopt or not to adopt to these technologies have largely focused on individual farmers' perceptions obtained by carrying out household surveys. These studies have ignored the crucial decision of geographical space as an important factor influencing the farmers' decisions and adoption of SOC enhancement technologies. Mercer (2004) recommends for a study covering the factors influencing adoption and spatial analyses of adoption. Therefore, by employing a set of geographical techniques specifically geospatial regression models, using forest-based regression – random forest (RF)– and Geographically weighted regression (GWR), we attempt to examine the possible effect of geographical space on the relationship between adoption of selected SOC enhancing LM technologies and factors anticipated to affect farmers' decision to adopt SOC enhancement technologies.

In this study, RF was applied (using observed adoption data on Agroforestry, manure, grass strips, fertilizer, residue management, crop rotation and intercropping) to predict spatially, the adoption of each LM technology spatially across the study areas. GWR was then applied using the predicted adopted data to examine the spatial variations/ relationships between adoption and the factors that are known to affect the adoption of these technologies. This will allow us to explore continuous varying relationships over space between the adoption of SOC enhancing LM technologies and the factors that encourage or constrain adoption.

4.3 Materials and methods

4.3.1 Description of the study sites

For the description of the study areas, see Chapter Three

4.3.2 Field survey

Refer to chapter Three

4.3.2.1 Sampling Technique

For the sampling technique, refer to Chapter Three

4.3.2.2 Data and data Sources

Refer to Chapter Three

4.3.2.3 Dependent and explanatory variables

For Dependent and explanatory variables, refer to Chapter three.

4.3.3 Data analysis

Spatial data on adoption

Primary data used in this study were on the adoption of the various selected SOCETs as obtained from the household survey. This data was in a binary format where 1 signified the technology had been adopted in a specific plot of land in a farm and 0 meant the technology had not been adopted. To obtain a fraction of the farm where the technology had been adopted, the number of plots under a technology were divided by the total number of plots in the farm in excel. Each farm represented by a specific household was geographically referenced enabling the development of a shapefile with a value of the previously calculated fraction representing the proportion of the farm under the technology. This was done for each SOCET and would represent the dependent variable. The explanatory variables on the other hand, were developed based on the driving factors to adoption or the factors affecting adoption of each SOCET predicted by a running a Probit model (refer to Chapter three) which was further enriched with data on factors affecting adoption of each SOCET from existing literature on studies carried out in the SSA for the purpose of modelling, as with more variables are more accurate predictions. The data was then obtained as GIS layers from secondary sources and covering the study areas. For those that were not available, proxies were used and some developed from documented sources at a fine resolution as shown in table 4.2. The data on table 4.2 represents both the data obtained from both Probit model and literature.

Table 4.2 variables of factors affecting adoption of SOCETs obtained for modelling with their sources and proxies.

Kenya

Agroforestry	Factors affecting adoption	Data source	Proxy (if any)	citation
	Education level of the hh head	KNBS, Kenya MOE	Distance to schools and	(Kuntashula and Mafongoya, 2005)

			educational centers	(Thangata and Alavalapati, 2003)
	Farming experience			(Meijer et al., 2015) (Franzel et al., 2001)
	Rainfall	Worldclim		(Holden, 1993) (El and Muneer, 2008) (Nkamleu and Manyong, 2008)
	Soil fertility	ISRIC	Soil organic carbon	(Meijer et al., 2015) (Kabwe, 2010)
	Erosion perception	RUSLE (Oliveira et al., 2015)		(Caveness and Kurtz, 1993)
	Access to credit	Google earth, CBK	Distance to banks, credit centers	(Nkamleu and Manyong, 2008)
	Access to extension	http://www.nafis.go.ke/	Distance to extension offices	(Nkamleu and Manyong, 2008 ; El and Muneer, 2008)
	Distance to market	Geonames	Distance to towns	(Nkamleu and Manyong, 2008)
	Household size			(Nkamleu and Manyong, 2008)
	Slope of the plot	Calculated from DEM	Earth explorer	
Fertilizer	Group membership			(Isham, 2002) (Minot et al., 2000)
	Soil fertility	ISRIC	Soil organic carbon	(Mwangi, 1996)
	Access to credit	Google earth, CBK	Distance to banks, credit centers	(Onyenweaku et al., 2007; Waithaka et al., 2007)
	Access to extension	http://www.nafis.go.ke/	Distance to extension offices	(Olwande et al., 2009; Reardon et al., 1999)
	Rainfall	Worldclim		(Waithaka et al., 2007)
	Plot size	Global field sizes		(Onyenweaku et al., 2007; Olwande et al., 2009)

	Distance to market	Geonames	Distance to towns	(Olwande et al., 2009)
	Household size			(Onyenweaku et al., 2007)
	Education level of the hh head	KNBS, Kenya MOE	Distance to schools and educational centers	(Onyenweaku et al., 2007; Waithaka et al., 2007)
	Farming experience			(Mwangi, 1996; Deressa et al., 2009)
Manure				
	Tenure security			(Kassie et al., 2013) (Ajayi et al., 2007)
	Plot fertility	ISRIC	Soil organic carbon	(Ajayi et al., 2007)
	Access to extension	http://www.nafis.go.ke/	Distance to extension offices	(Mkhabela and Materechera, 2003; Mustafa-Msukwa et al., 2011)
	Plot size	Global field sizes		(Mkhabela and Materechera, 2003; Williams, 1999; Marenya and Barrett, 2007)
	Education level of the hh head	KNBS, Kenya MOE	Distance to schools and educational centers	(Waithaka et al., 2007; Mkhabela and Materechera, 2003; Mustafa-Msukwa et al., 2011)
	Household size			(Ajayi et al., 2007) (Mkhabela and Materechera, 2003; Marenya and Barrett, 2007)
	Distance to market	Geonames	Distance to towns	(Mustafa-Msukwa et al., 2011)
	Group membership			(Materechera, 2010; Waithaka et al., 2007)
	Soil fertility	ISRIC	Soil organic carbon	(Materechera, 2010)

	Access to credit	Google earth, CBK	Distance to banks, credit centers	(Ajayi et al., 2007; Waithaka et al., 2007; Marenya and Barrett, 2007)
	Livestock ownership	Livestock density (FAO 2005)		(Williams, 1999; Marenya and Barrett, 2007)
	Rainfall	WorldClim		(Waithaka et al., 2007)
	Plot distance			(Ajayi et al., 2007; Williams, 1999)
Intercropping				
	Soil fertility	ISRIC	Soil organic carbon	(Ketema and Bauer, 2012)
	Access to extension	http://www.nafis.go.ke/	Distance to extension offices	(Almitu.M.A., 2011; Thangata & Alavalapati, 2003)
	Distance to market	Geonames	Distance to towns	(Almitu.M.A., 2011; Ketema and Bauer, 2012)
	Education of hh head	KNBS, Kenya MOE	Distance to schools and educational centers	(Almitu.M.A., 2011)
	Household size			(Thangata and Alavalapati, 2003)
Grass strips				
	Erosion perception	RUSLE (Oliveira et al., 2015)		(Van Den Berg, 2013)
	Soil fertility	ISRIC	Soil organic carbon	(Tenge et al., 2004; Sietz and Van Dijk, 2015)
	Access to credit	Google earth, CBK	Distance to banks, credit centers	(Van Den Berg, 2013) (Mureithi et al., 1998; Tenge et al., 2004)
	Access to extension	http://www.nafis.go.ke/	Distance to extension offices	(Mureithi et al., 1998)
	Livestock ownership	Livestock density (FAO 2005)		(Mureithi et al., 1998)
	Plot size	Global field sizes		(Van Den Berg, 2013; Mureithi et al., 1998)

	Education level of the hh head	KNBS, Kenya MOE	Distance to schools and educational centers	(Tenge et al., 2004)
	Slope of the plot	DEM – earthexplorer.org		(Van Den Berg, 2013)
Residue management				
	Household size			(Adeoti and Barry, 2006)
	Soil fertility	ISRIC	Soil organic carbon	(Mango et al., 2017)
	Access to credit	Google earth, CBK	Distance to banks, credit centers	(Rockstrom et al., 2003)
	Access to extension	http://www.nafis.go.ke/	Distance to extension offices	(Valbuena et al., 2012)
	Education level of the hh head	KNBS, Kenya MOE	Distance to schools and educational centers	(Erenstein, 2002)
	Livestock ownership	Livestock density (FAO 2005)		(Erenstein, 2003)
	Plot distance	Global field sizes		(Mango et al., 2017)

Ethiopia

Fertilizer				
	Plot fertility	ISRIC	Soil organic carbon	(Tsehaye, 2008; Onyenweaku et al., 2007)
	Education level of the hh head	Google earth	Distance to schools and educational centers	(Waithaka et al., 2007; Omamo et al. 2002)
	Access to extension	Google earth	Distance to extension offices	(Eba & Bashargo 2014)

	Soil erosion	RUSLE (Oliveira et al., 2015)		(Van Den Berg, 2013)
	Farmers experience			(Eba & Bashargo 2014)
	Slope of the plot	DEM – earthexplorer.org		(Aemro and Musa, 2016)
	Rainfall			(Tsehaye, 2008)
	Distance to market	Geonames	Distance to towns	(Waithaka et al., 2007; Gebresilassie and Bekele, 2015)
	Plot size	Global field sizes		(Onyenweaku et al., 2007) (Olwande et al., 2009)
	Household size			(Tchale et al. 2004),
	Access to credit	Google earth	Distance to banks, credit centers	(Onyenweaku et al., 2007) (Waithaka et al., 2007)
Manure				
	Distance to market	Geonames	Distance to towns	(Mwangi, 1996)
	Education level of the hh head	Google earth	Distance to schools and educational centers	(Mustafa-Msukwa et al., 2011)
	HH size			(Kammer, 2014)
	Farmers experience			(Liu et al., 2006)
	Access to extension	Google earth	Distance to extension offices	(Kenea et al., 2000; Tsehaye, 2008)
	Access to credit	Google earth	Distance to banks, credit centers	(Gachene and Wortmann, 2007)
	Group membership			(Mwangi, 1996)
	Soil erosion	RUSLE (Oliveira et al., 2015)		(Larney and Janzen, 1996)
	Rainfall	WorldClim		(Paulus, 2015)

	Slope of the plot	DEM – earthexplorer.org		(Larney and Janzen, 1996)
	Distance to plot			(Waithaka et al., 2007; Giller et al., 2006
Crop rotation				
	Access to extension	Google earth	Distance to extension offices	(Almitu.M.A., 2011)
	Tenure security			(IIRR, 1995)
	Education level of the hh head	Google earth	Distance to schools and educational centers	(Almitu.M.A., 2011)
	Farming experience			(Kelsey, 2013)
	Plot size	Global field sizes		(Ketema & Bauer, 2012)
	Access to credit	Google earth	Distance to banks, credit centers	(Kenea et al., 2000)
	Soil erosion	RUSLE (Oliveira et al., 2015)		
	Rain	WorldClim		
	HH size			
	Slope	DEM – earthexplorer.org		
Grass strips				
	Distance to market	Geonames	Distance to towns	
	Tenure security			(Mugure et al., 2013)
	Household size			(Sood, 2006; Clay, Reardon, & Kangasniemi, 1998)
	Farming experience			(Tenge et al., 2004)
	Soil fertility	ISRIC	Soil organic carbon	(Tenge et al., 2004) (Semgalawe 1998)

	Access to extension	Google earth	Distance to extension offices	(Kammer, 2014; Eba & Bashargo 2014)
	Slope	DEM – earthexplorer.org		(Tenge et al., 2004)
	Access to credit	Google earth	Distance to banks, credit centers	(Kammer, 2014)
	Rainfall	WorldClim		IIRR (1995)
	Plot size	Global field sizes		(Irungu, 1998)
Residue management				
	Distance to plot			(Kelsey, 2013)
	Plot size	Global field sizes		(Mugure et al., 2013)
	Household size			(Kammer, 2014)
	Soil fertility	ISRIC	Soil organic carbon	(Odendo et al. 2011)
	Soil erosion	RUSLE (Oliveira et al., 2015)		(IIRR, 1995)
	Tenure security			(Mugure et al., 2013)
	Slope	Global field sizes		(IIRR, 1995)
	Education level of the hh head	Google earth	Distance to schools and educational centers	(Brown, 1991)
	Group membership			(Liu et al., 2018)
	Access to extension	Google earth	Distance to extension offices	(Kammer, 2014)

4.3.4 The Models (Random Forest model and Geographically weighted regression model)

Modelling was done in two steps, using the Random Forest (RF) model and using Geographically Weighted Regression (GWR). The RF algorithm is a non-parametric statistical method that uses a bagging-based technique to construct a series or an ensemble of classification or regression trees (i.e., sampling from the original data set with replacement) (Breiman 2001), averaging the result of many decision trees and therefore, reducing the variance while maintaining low bias (see equation 4.1). Based on discrete or continuous variables, the algorithm can achieve high predictive accuracy (Adam et al. 2012). GWR (see equations 4.2 to 4.4) explores spatial variations by allowing variables of the regression model (e.g., slope, distance, intercept) to change from one location to another, and generate location-specific coefficient maps which contribute to more appropriate descriptions and predictions for local points (Foody, 2003).

The first step involved random forest (RF) where using the adoption data as the dependent variable and the developed data of factors affecting adoption of SOCETs as explanatory variables (table 4.2), RF model was used to predict adoption of each SOCET across space at a fine resolution of 100m from the point data to a raster data. This resulted into maps of different SOCETs as shown in figure 4.3. The maps show adoption in a spatial representation and gives the proportion of technology adoption of each specific SOCET in each pixel and covers the whole area of study.

The second step involved using the adoption data developed from prediction in RF for each SOCET as a dependent variable and the developed explanatory variable as in table 4.2. Here, GWR was used to predict the effect of each explanatory variable on the adoption of SOCETs as predicted from RF across space on the study areas. The result was maps of the effect of the variables on the adoption of SOCETs as shown in figures 4.4 to 4.15.

4.3.5 Modelling techniques

4.3.5.1 Random Forests

RF is a regression approach that combines multiple decision trees (DT) algorithm performance to predict the value of a variable (Breiman, 2001; Guo et al., 2011; Rodriguez-Galiano et al., 2012b). That is when an *(x)* input vector, made up of the values of the various proof characteristics evaluated for a given training field, is generated by RF. A number K of regression trees $\{T(x)\}_1^K$ are constructed by RF and the results are averaged. The predictor of RF regression after K such trees are grown is:

$$\hat{f}_{rf}^{K}(x) = \frac{1}{K}\sum_{k=1}^{K} T(x). \qquad \textbf{(4.1)}$$

RF increases the variety of the trees to avoid the correlation of the multiple trees by letting them grow from distinct training data subsets generated by a process called bagging. Bagging is a method used to produce training data by randomly resampling the original dataset with a substitution, i.e., Without eliminating the data from the input sample chosen to produce the next subset, $\{h(x, \Theta_k), k = 1, \ldots, K\}$, where $\{\Theta_k\}$ are independent random vectors with the same distribution. Therefore, some data can be used in training more than once, while others may never be used. More accuracy is thus obtained, as it makes it more robust when dealing with small differences in input data and at the same time improves the precision of estimation (Breiman, 2001). On the other hand, when the RF makes a tree grow, it uses the best feature/split point within a subset of evidential features which has been selected randomly from the overall set of input evidential features. Therefore, this can decrease the strength of every single tree, but it reduces the correlation between the trees, which reduces the generalization error (Breiman, 2001). With no pruning, the trees of a RF classifier grow, which makes them light, from a computational point of view. In addition, the samples not chosen in the bagging process for the training of the k-th tree are used as part of another subset called out-of-bag (oob). The k-th tree will use these oob elements to assess output (Peters et al., 2007). RF will thus measure an unbiased generalization error calculation without the use of an arbitrary text data subset (Breiman, 2001). If the number of trees increases, the generalization error converges; the RF therefore does not overfit the data. RF also offers an evaluation of the relative significance of the various evidential features. This concept is useful for multi-source research, where data dimensionality is very high, and in order to be able to pick the right proof elements, it is necessary to know how each attribute affects the prediction model (Gislason et al., 2006; Pal, 2005). The RF switches one of the input evidential features to determine the value of each component (e.g., satellite image band) while holding the others constant, and calculates the decrease in precision that has occurred by the calculation of the oob error (Breiman, 2001).

4.3.5.2 Geographically Weighted Regression

Geographically weighted regression (GWR) enables modelled relationships to vary geographically across a sample region between the response variable and a set of covariates (Harris et al., 2010), thereby enabling spatial variability to be defined and spatial non-stationarity to be accommodated. Geographically weighted regression expands the conventional standard regression paradigm by allowing local parameters to be calculated rather than global ones (Fotheringham et al., 2002). It is a type of local statistics, which can produce a set of local parameter estimates showing how a relationship varies over space and then to examine the spatial pattern of the local estimates to get some understanding of hidden possible causes of this pattern (Fotheringham et al., 2002). On the other hand, ordinary least squares (OLS) is a type of global statistics, which assumes the relationship under study is constant over space, so the parameter is estimated to be the same for all the study area. To assist in identifying the best set of driving variables GWR models, OLS regression models were adopted at first, to study the relationships between adoption and potential SOCETs. In OLS, the variables that showed multi-collinearity and/or redundancy were dropped for GWR.

The OLS regression model is expressed as:

$$y = \beta_0 + \sum_{i=1}^{p} \beta_i x_i + \varepsilon \tag{4.2}$$

where y is the dependent variable (adoption); x_i represents the independent variable (drivingfactors); β_0 and β_i represent the intercept and slope coefficient, respectively; p denotes the number of independent variables; and ε is the random error term. Conventional OLS regression models are assumed to apply global parameters over a region which may limit the descriptive and predictive utility of understanding and planning local urban areas. GWR extends the OLS and identifies spatially varying relationships by generating local slope coefficients that can be mapped to show their spatial variability. GWR encourages coefficients to vary consistently over the area of study, and it is possible to approximate a set of coefficients at any position usually on a grid, so that a coefficient surface can be visualized and tested for relationship heterogeneity. GWR can be expressed as

$$y_j = \beta_0(u_j, v_j) + \sum_{i=1}^{p} \beta_i(u_j, v_j) x_{ij} + \varepsilon_j \tag{4.3}$$

where u_j and v_j are the coordinates for each location *j*, $\beta_0(u_j, v_j)$ is the intercept for location *j*, $\beta_i(u_j, v_j)$ is the approximation of the local parameter for the independent variable at position j. GWR is calibrated using a distance decay function by weighting all observations around a sample point, meaning that the observations closest to the sample point position have a larger effect on the local parameter estimates for the location. Using the exponential distance decay form, the weighting function can be stated:

$$w_{ij} = exp\left(-d_{ij}^2 / b^2\right) \tag{4.4}$$

Where; w_{ij} is the weight of observation *j* for observation i, d_{ij} is the distance between observation *i* and *j*, *b* is the kernel bandwidth. The weight rapidly reduces to zero when the distance is greater than the kernel bandwidth. For GWR, it is possible to select both fixed and adaptive kernel bandwidth. The fixed kernel has a constant bandwidth over space, while the adaptive kernel will adjust the size of bandwidths to data density variations such that bandwidths become larger in areas where data are sparse and smaller where data is denser. We used adaptive kernel bandwidth in this study, because sample density varies over the study area. The optimal bandwidth was determined by minimizing the corrected Akaike Information Criterion (AICc) as described in Fortheringham et al. (2002). GWR models produce a set of local regression results including local parameter estimates, the values of t-test on the local parameter estimates, the local R^2 values, and the local residuals, which can all be mapped to show their spatial variability.

Higher R^2 means that independent variable can explain more variance in dependent variable. A lower AICc value indicates a closer approximation of the model to reality, so lower AICc means better model performance (Wang et al.,2005).

Both OLS and GWR models were performed using adoption of each SOCET as the dependent variables and factors affecting adoption as independent/explanatory variables.

4.4 Results and discussion

Variables such as plot sizes which were represented by global field sizes data, were dropped during regression model specification across all practices since they were highly correlated indicating multi-collinearity among the variables, other variables such as tenure security, farming experience, household sizes, group membership and distance to plots were not represented in the regression models because the data was not available from secondary sources. However, this does not mean that these variables have no relationship with adoption of SOC enhancing land management technologies.

4.4.1 Spatial distribution of adoption from RF

The spatial distribution of adoption of agroforestry, manure, intercropping, fertilizer, residue management and grass strips for both Kenya and Ethiopia are shown in figures 4.1 and 4.2 below.

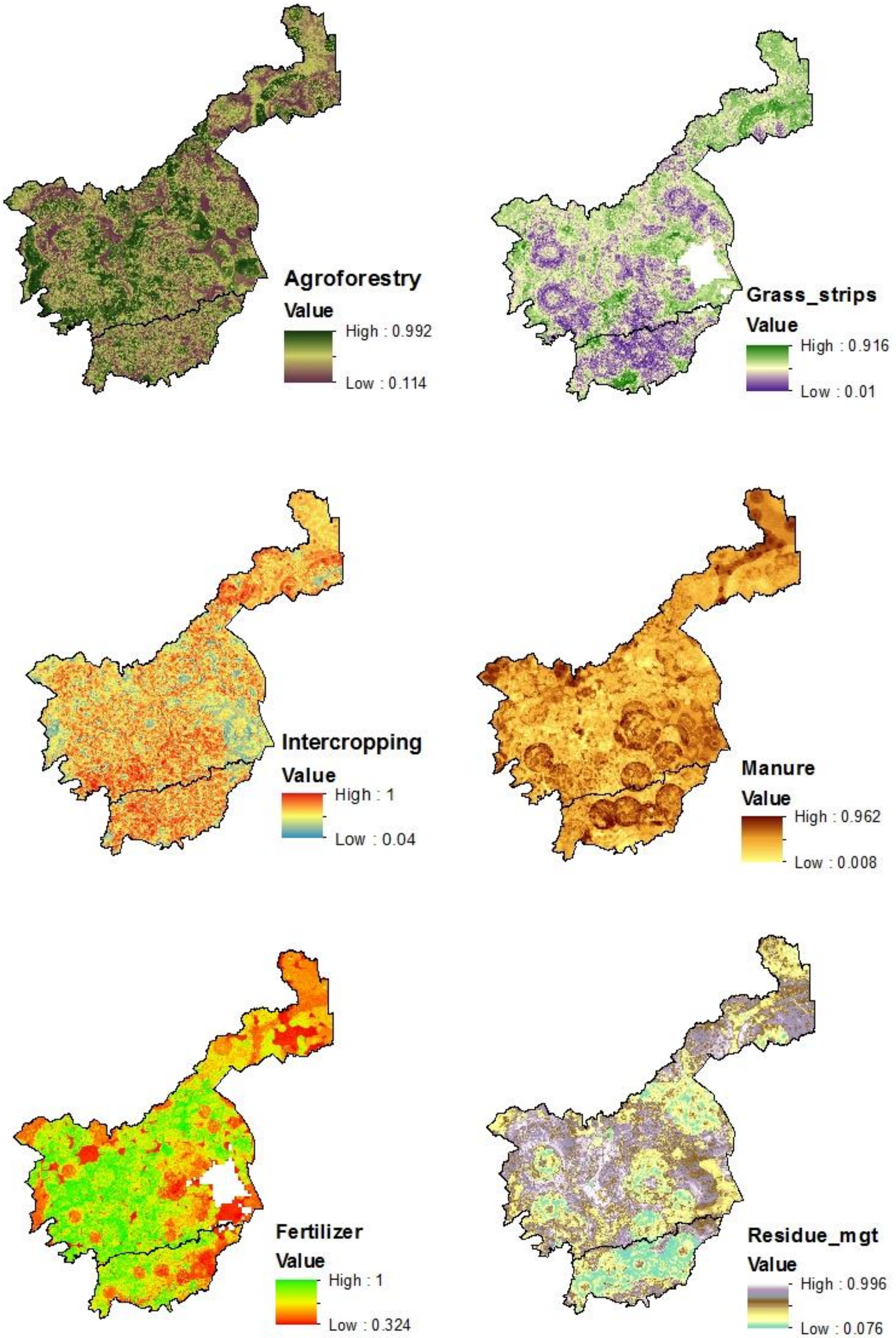

Figure 4.3: maps showing spatial adoption of various land management technologies across western Kenya, Vihiga and Kakamega counties.

In Kenya, there is high adoption of agroforestry in the western areas of Kakamega and many patches can be seen in the middle, to the North and the areas around Kakamega forest while in Vihiga county adoption is about 50% and above with lower adoption seen in the eastern areas. This is as a result of agroforestry campaigns being carried out in Kenya by the government and non-governmental organizations to increase tree cover and improve soil fertility (Kiptot, 2007). Adoption of grass strips in Kenya is high in areas to the south of Vihiga county and north, western and north eastern parts of Kakamega and areas around Kakamega forest. This is carried out in areas with high slopes to control erosion and also to provide animal feeds (Orodho, 2006). Intercropping is highly practiced in western Kenya and low only in the areas around Kakamega forest. This supports the fact that most farmers in western Kenya practice intercropping and especially of maize and legumes. Manure adoption is moderate and well distributed in both Kakamega and Vihiga counties with low adoption being seen in the central areas of Kakamega county. Fertilizer is highly adopted in Kenya with low adoption being experienced in areas around Kakamega forest, to the north of Kakamega county and eastern parts of Vihiga counties. This supports the fact that most farmers in Western Kenya use manure on their farms. This is because of the influence of organizations providing extension as well as provision of subsidized fertilizers. Residue management which is measured by farmers leaving at least 30% of their residues on farm is high in the central areas of Kakamega county, very low in Vihiga county and moderately high in most parts of Kakamega county.

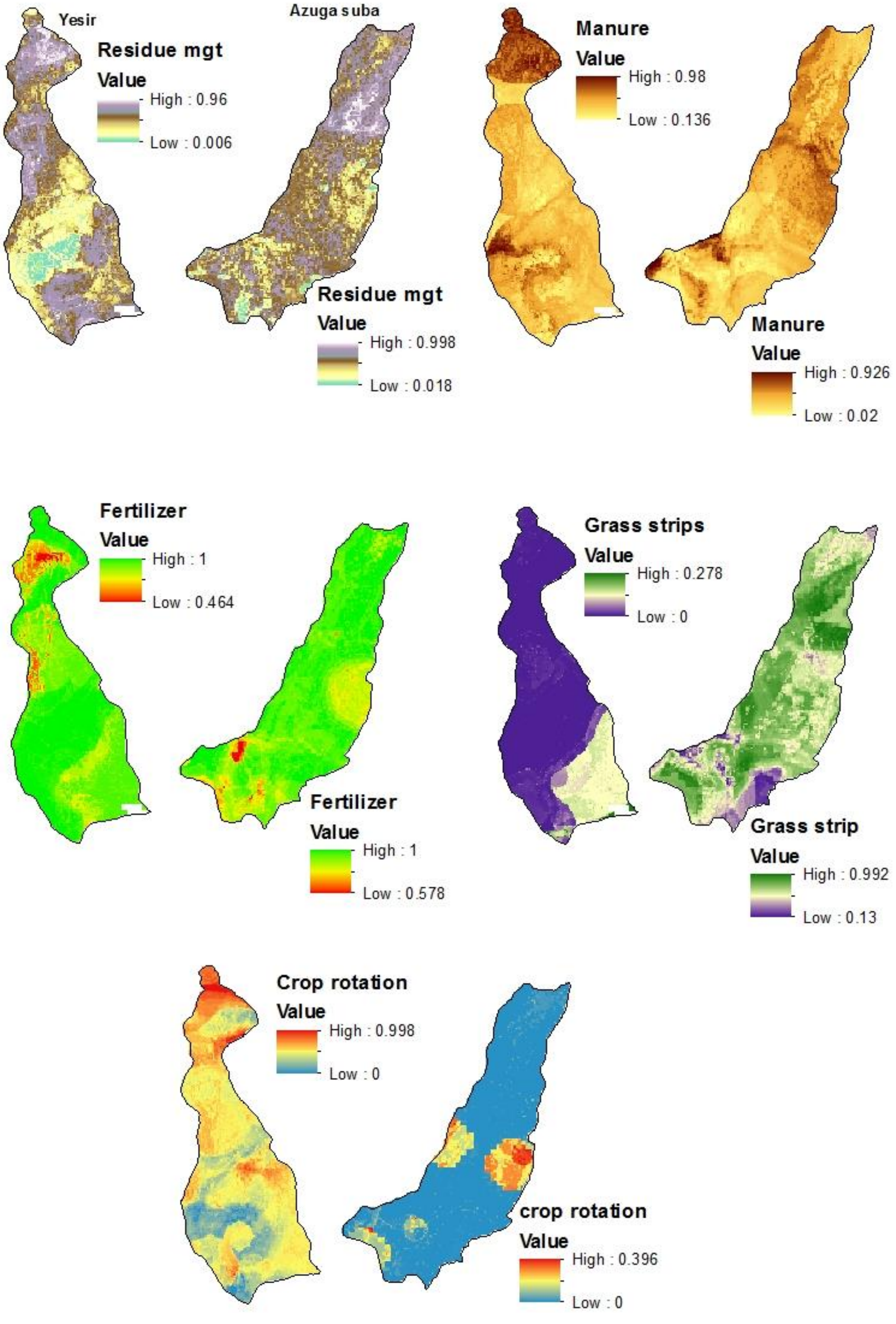

Figure 4.4: maps showing adoption of various land management technologies across Ethiopian Yesir and Azuga-suba watersheds.

In Ethiopia, adoption to residue management is high in north and southern areas of Yesir and Azuga-Suba and low in the central areas of Yesir and the southern tip of Azuga-Suba. High adoption is as a result of presence of high amount of teff, wheat and barley residue and extension officers who encourage leaving residues on farm to improve fertility as well as reduce soil erosion. Manure adoption is very high in the northern areas of Yesir while the other areas have low adoption except some parts to the western of Yesir. The north of Azuga-Suba exhibits high adoption of manure which reduces as you go to the south. Contrary to the adoption of manure, fertilizer adoption is very high in both Yesir and Azuga-Suba except in some parts of north Yesir which is Jib-gedel and to the south of Azuga-Suba. Grass strips adoption is very low in Yesir with moderate adoption to the south, while adoption of grass strips is high in Azuga-Suba with low adoption to the south. Low adoption of grass strips in Ethiopia is as a result of their main crops being teff, wheat and barley which are of the grass family. Crop rotation is highly practiced in Yesir and lowly practiced in Azuga-Suba.

4.4.2 Factors affecting adoption of SOCETs

With the factors affecting the adoption of each SOCET known and after the selection based on the availability of data. Below are maps and description of how each factor affects the adoption of each SOCET across space.

In the figures, some areas of the study areas show a positive value of the t-surface or a negative value to each of the driving factors. The t surface gives a relationship of the adoption of the technology to the driving factors. A positive t-surface means that, increase in the value of the driving factor leads increased adoption and vice versa. Other areas show negative t-surface values which means that an increase in the value of the driving factor leads to decreased adoption of a technology and vice-versa. The magnitude of the effect of each t-surface to the negative or positive side is shown by how high positive or low negative the value is. Higher positive means higher effect to adoption.

4.4.2.1 Agroforestry

Agroforestry was significant in Kenya. The driving factors of the adoption to agroforestry include, access to credit, education level of the households’ head, erosion, access to extension, distance to markets, slope and soil fertility perception. The t-surface for the driving factors is shown in figure 4.3. From the figure, access to credit affects 40% of the study area positively to the adoption of agroforestry. This implies that farmers with credit in the areas affected positively are more likely to adopt to agroforestry when they have access to credit. This is in line with Zerihun et al., 2014 who found out that farmers require credit to adopt agroforestry. However, about 60% percentage of the area is being affected negatively by credit meaning that access to credit services leads to low adoption of agroforestry. This is because credit enables the farmers to practice other soil carbon enhancing technologies other than agroforestry.

In a similar manner, about 50% of the study area has access to education, soil erosion perception and access to extension affecting adoption to agroforestry negatively and 50% positively. 70% of the area has soil fertility perception affecting agroforestry positively. 60% of the study area has access to markets and slope of the plot affecting adoption positively meaning that in these areas, farmers who have access to markets and those whose plots have high slopes are more likely to adopt to agroforestry in comparison to the remaining 40% which is affected negatively. Therefore, in most areas, farmers with high level of education, those perceiving erosion to be a problem, those having access to extension, those having access to markets and where plots are sloppy are more likely to adopt to agroforestry. This is in line with the findings of Lambert& Ozioma (2012), that literacy and the persuasion and conviction by extension agents favored the adoption of agroforestry innovations. This led to improved knowledge of agroforestry in reducing soil erosion and caring for plots on high slopes susceptible to erosion and landslides. Market access enabled farmers to access and purchase inputs easily. For areas having negative effects, high level of education, perceiving soil erosion to be a problem, having access to extension, ease of access to markets and high plot slopes discourages adoption to agroforestry but at lower percentage. This is in line with Mwase et al. (2015), that education, access to extension and access to seedlings and inputs are of paramount importance to the adoption of agroforestry by farmers.

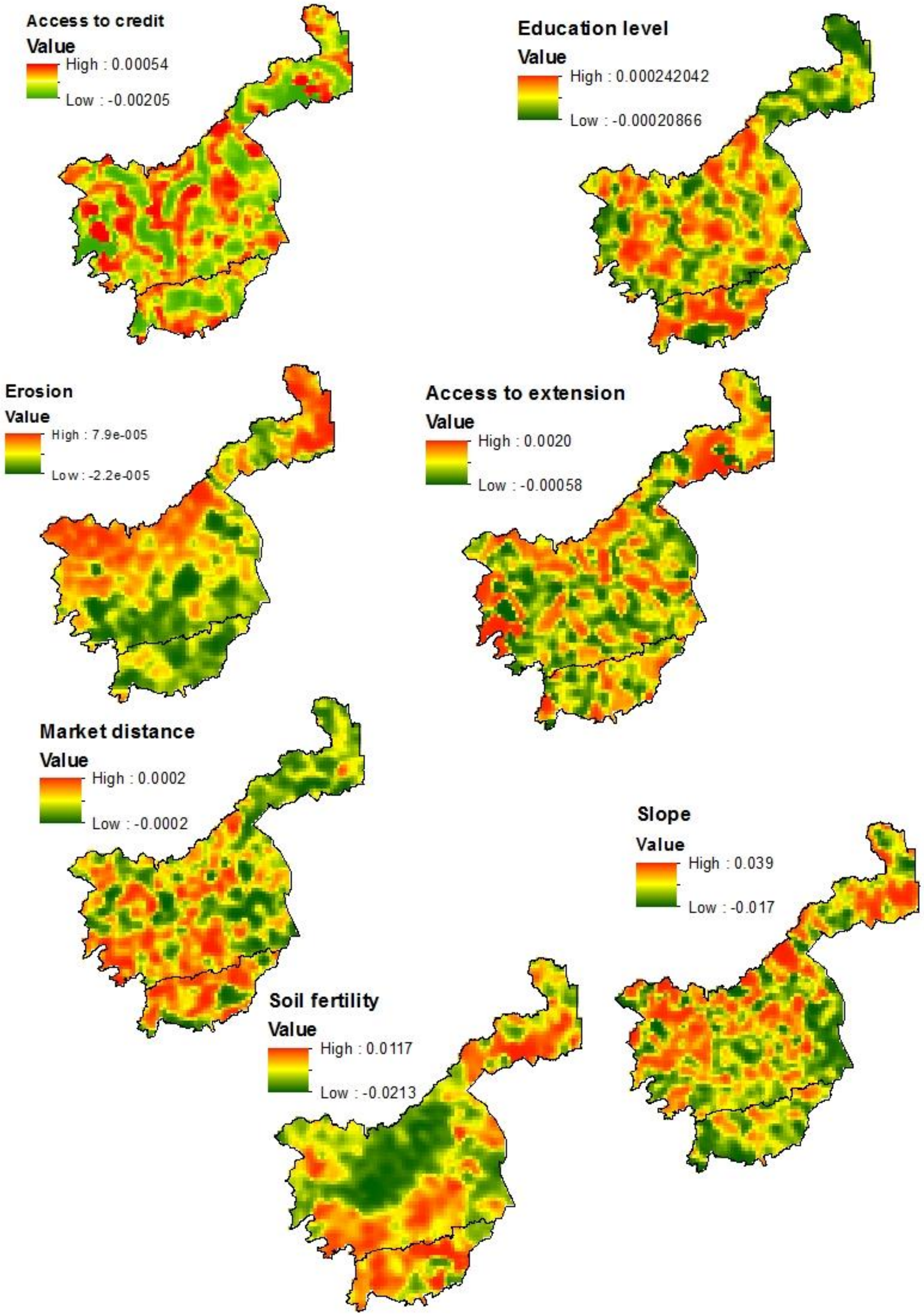

Figure 4.5: maps showing t-surface for the factors affecting the adoption of agroforestry in western Kenya.

4.4.2.2 Fertilizer

The driving factors of the adoption to fertilizer in Kenya include; access to credit, soil erosion perception, access to extension, distance to markets, rainfall and soil fertility perception. In Ethiopia, the factors include; education level of the household head, soil erosion perception, access to extension, distance to market, slope of the plot, rainfall and soil fertility perception. The t-surface for the driving factors is shown in figures 4.4 and 4.5. Although the effects of these factors vary from highly negative to highly positive, these factors affect the adoption of fertilizer positively in most parts of Vihiga and Kakamega counties. Access to credit, education level of the household head and access to extension has a high positive effect to adoption while erosion perception and distance to markets has a medium positive effect and soil fertility perception and rainfall has a low positive effect. This implies that with more access to credit, markets and extension, high level of education of the household head, perception that soil erosion is a problem, perception that the soil is fertile or higher amounts of rainfall comes higher adoption. Contrary to this, the border parts of both counties show negative effects of the driving factors with a negative t-surface value as shown in figure 4.4 below.

In Ethiopia, on the other hand education level affects a 99% of Yesir watershed positively. This implies that a high education levels of the household head leads to high adoption. This is in line with Waithaka et al (2007), that high education level of the household head leads to increased amount of fertilizer used arising from a better understanding of the importance of fertilizers. In Azuga-suba the effect of education level varies with the majority being positive ranging from lower positive to higher positive. Erosion perception affects 99%of Yesir negatively implying that where there is erosion is less adoption. Similarly, about 50% of Azuga-suba has a negative effect with a 50% positive implying that where there is erosion is high fertilizer addition. Access to extension services affects 99% of Yesir positively implying that with extension is high adoption. Contrary to Yesir extension affects 50% of Azuga-suba negatively implying that with extension is less adoption probably because they encourage organic manure use. Market access affects Yesir 99% positively, implying that access to markets leads to high adoption of fertilizer. This is in line with Waithaka et al (2007), that ease of access to markets decreases the final costs of fertilizer enabling farmers to purchase. This varies in Azuga-suba with some areas having negative effects probably due to other economic factors such as lacking credit which improves the purchasing power of the farmers. Rainfall affects 99% of Yesir positively. This implies that with high rainfall is high fertilizer adoption. In Azuga-suba about 50% is negative implying that adoption is low with high rain probably due to soil erosion risk. Soil fertility perception affects 95% of Yesir positively implying that with fertile soils there is high adoption. In Azuga-suba about 40% is negative implying that farmers apply fertilizer when the soil is not fertile.

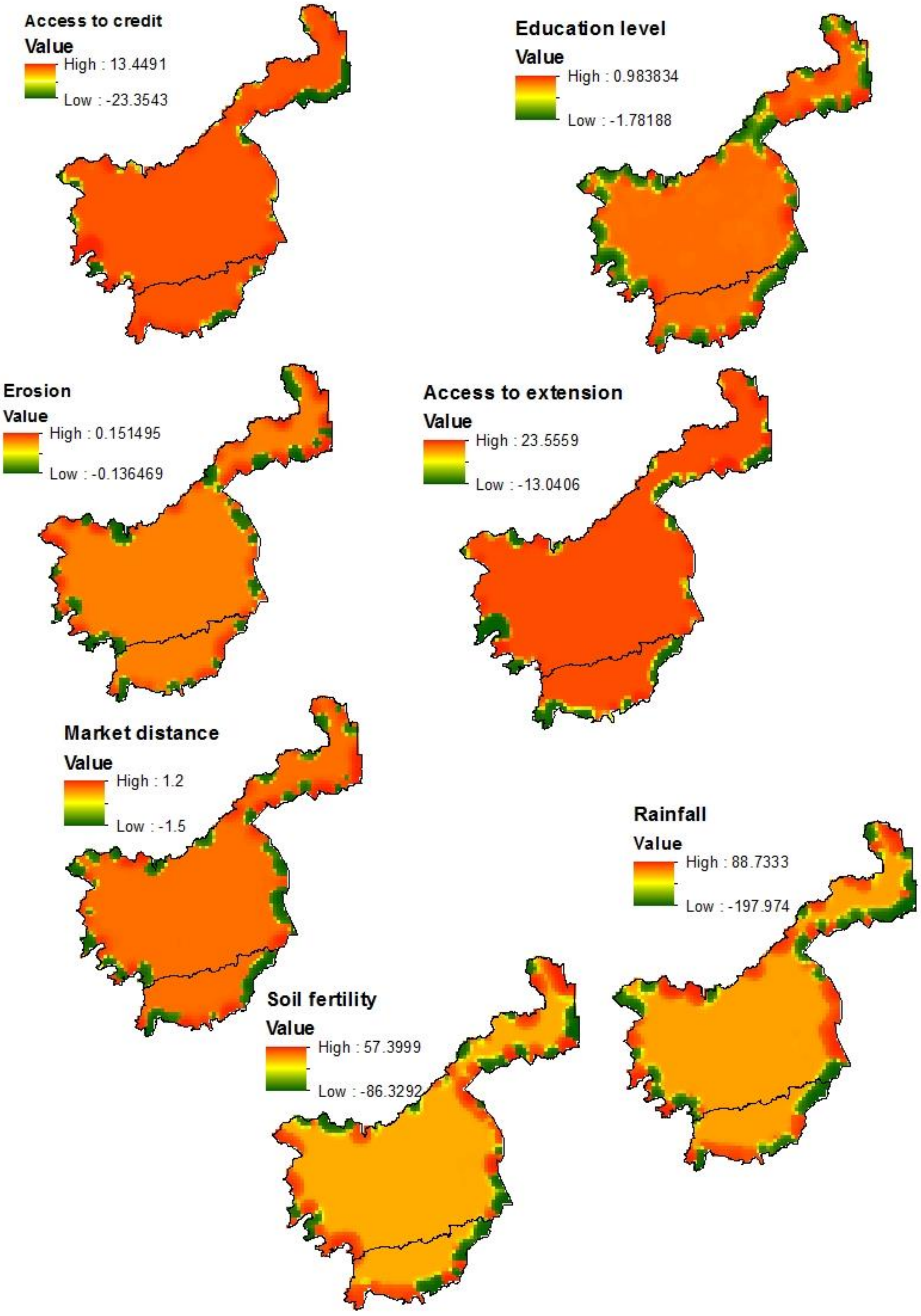

Figure 4.6: maps showing t-surface for the factors affecting the adoption of fertilizer in western Kenya

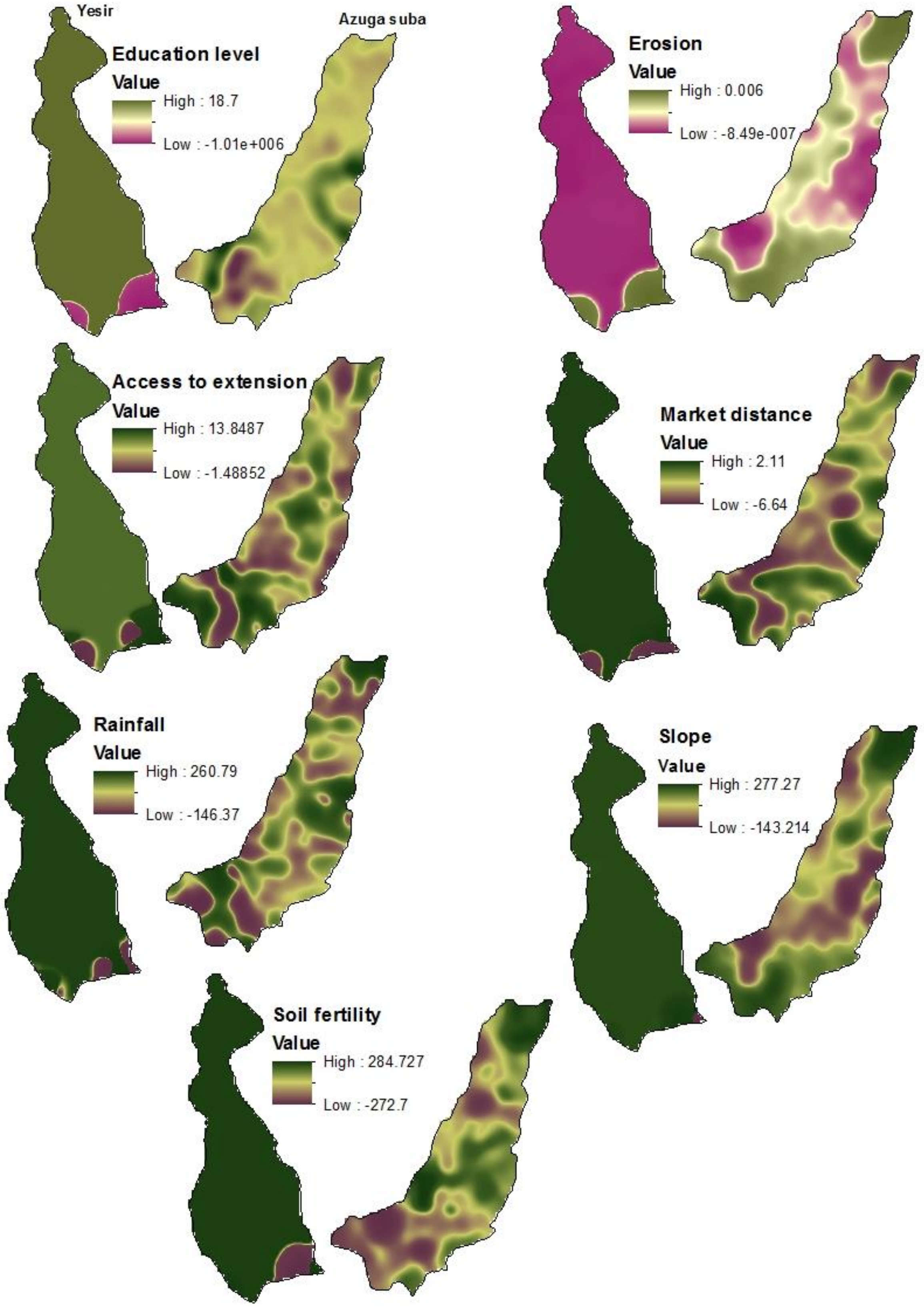

Figure 4.7: maps showing t-surface for the factors affecting the adoption of fertilizer in Ethiopia

4.4.2.3 Intercropping and crop rotation

Intercropping is significant in Kenya and Crop rotation in Ethiopia. Intercropping adoption in Kenya was affected by; distance to market, access to extension, level of education and soil fertility perception. On the other hand, adoption to crop rotation adoption in Ethiopia was affected by level of education, erosion perception, access to extension, access to credit, rainfall and plot slope. The t-surface for the driving factors is shown in figures 4.6 and 4.7.

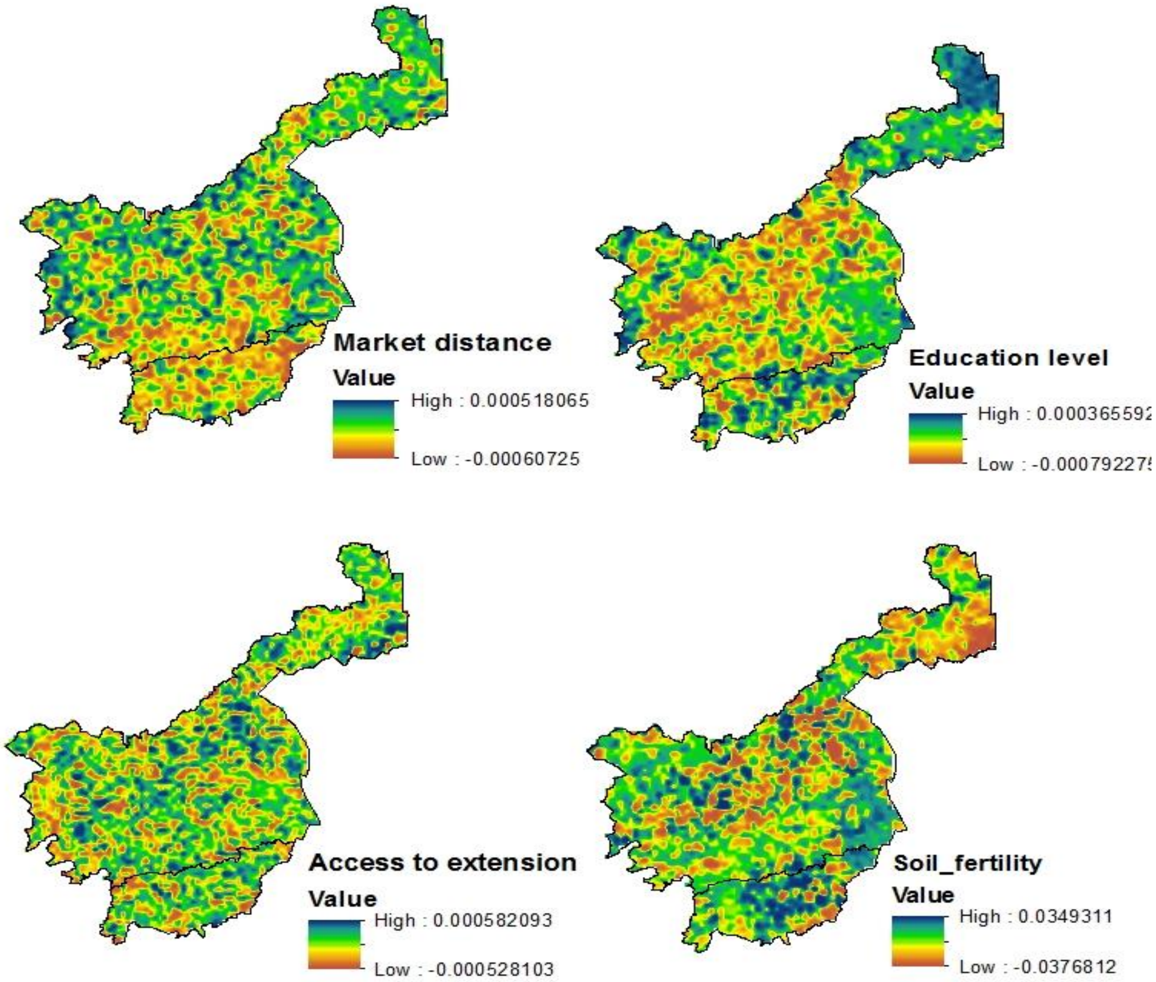

Figure 4.8: maps showing t-surface for the factors affecting the adoption of intercropping in Western Kenya

In Kenya, access to market affects about 60% of Kakamega county positively. This means that access to markets leads to high adoption of intercropping, probably due to ease of access of seeds and other inputs. It also affects 80% of Vihiga county negatively meaning that with access to markets leads to low adoption of intercropping. Level of education affects 50% of Kakamega and 80% of Vihiga county positively meaning that with high levels of education is more adoption of intercropping. Access to extension affects 70% of the study areas positively meaning that with extension is high adoption. Soil fertility on the other hand, affects 80% of the study area positively meaning that when the soil is fertile farmers adopt intercropping at high rates possibly so as to increase production not forgetting the lower percentage where farmers adopt intercropping highly when soil is not fertile.

In Ethiopia, education levels affect about 50% of both Yesir and Azuga-suba adoption to crop rotation positively meaning that farmers with high level of education in these areas adopt highly to crop rotation. Soil erosion perception affects70%of Yesir negatively and 50% of Azuga-suba. This means that in these areas where there is erosion there is low adoption. The other 50% of Azuga-suba is affected positively meaning that when there is plot erosion farmers adopt crops rotation. Access to extension, access to credit, rainfall and plot slope affects both Azuga-suba and Yesir at approximately 50% both positively and negatively. Positive effects imply that a farmer in these areas practice crop rotation whenever they have access to extension, access to credit, their area receives high rainfall and their plots are sloppy. On the other hand, a farmer who is on the areas where the factors affect negatively will most probably not adopt to crop rotation when he has access to extension, access to credit, their area receives high rainfall and their plots are sloppy. This is in line with Chomba (2004), who found out that intercropping and crop rotation are usually adopted as a risk reduction tactic in area receiving low rainfall. Farmers require credit to buy inputs and pay for labour as these methods require human capital (Chomba, 2004).

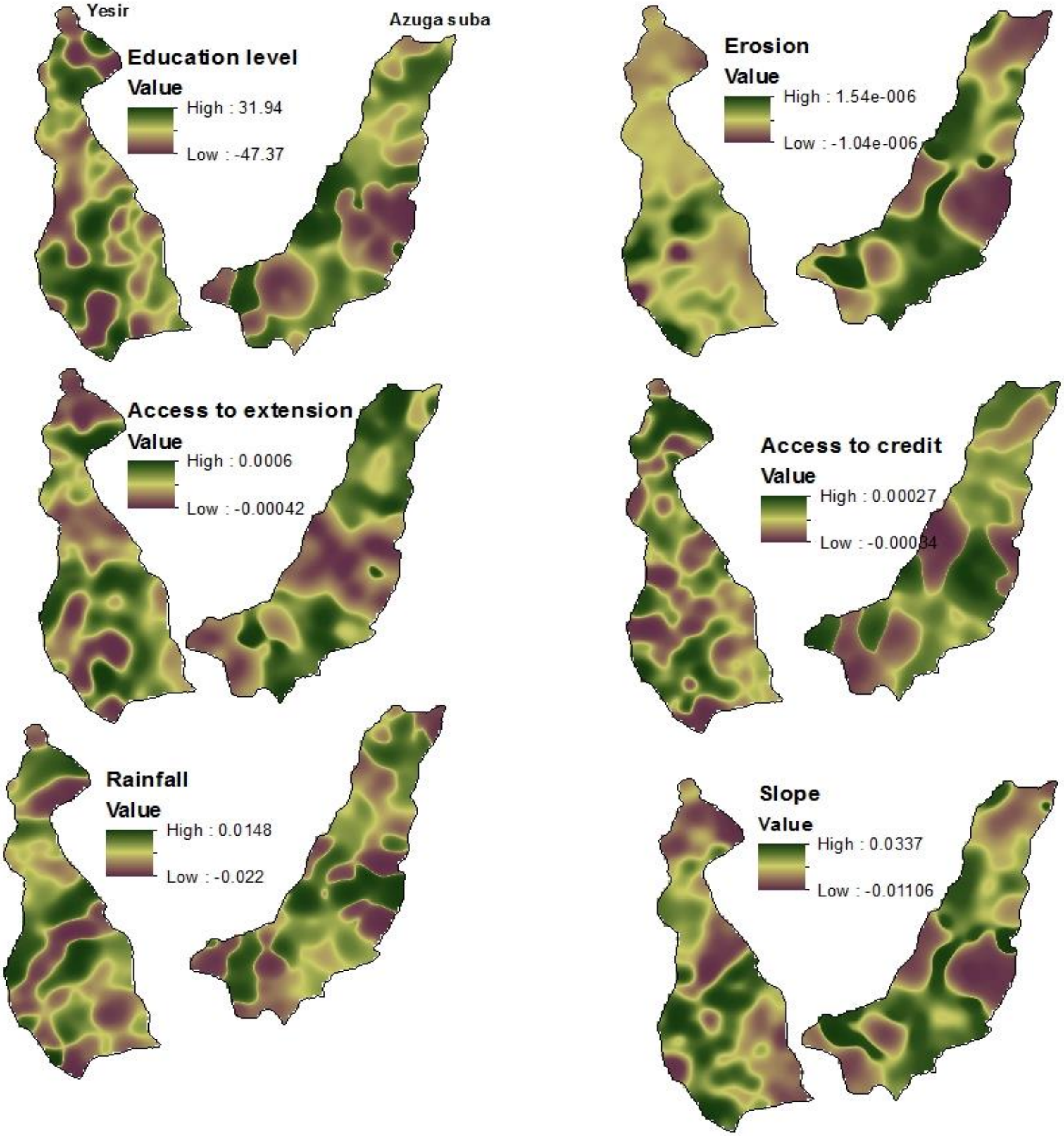

Figure 4.9: maps showing t-surface for the factors affecting the adoption of crop rotation in Ethiopia

4.4.2.4 Manure

The adoption to manure in Kenya was affected by access to credit, level of education, distance to the market, access to extension and plot fertility perception. In Ethiopia on the other hand adoption was affected by level of education, erosion, access to extension, distance to markets, rainfall, slope and access to credit. The t-surface for the driving factors is shown in figures 4.8 and 4.9. In Kenya, access to credit plays an important role in manure adoption with at least 50% of the study area being affected positively by credit. This implies that at least half of the area adopts manure use when they have credit. This is in line with Waithaka et al. (2007), that credit to pay for labour is required to carry and add manure to the farms. Education level affects 60% of the study area negatively meaning that with high education level is less adoption to manure use. This could have resulted from the farmers having more knowledge of soil fertility management technologies and therefore are able to adopt them together to improve their effects. Access to market has at least 50% positive effect on manure adoption. This implies that half of the study area experiences high manure adoption when they have access to market while the other 50% of the area experiences low adoption when they have good access to market. Low adoption can be attributed by presence of inorganic fertilizer stores in the market. Access to extension affects approximately 60% of the study area positively meaning that extension availability increases adoption of manure. In the remaining 40%, extension affects adoption negatively which implies that with extension is low adoption. This could be due to more options given to farmers by extension. Perception that the soil is fertile affects most of the study area negatively meaning that when the soil is fertile there is less adoption. In other areas it affects positively meaning that farmers adopt manure when the soil is fertile so as to maintain soil fertility.

In Ethiopia, the level of education affects 99% of Yesir and 50% of Azuga-suba positively meaning that with high level of education is increased fertilizer adoption. Contrary to this in Azuga-suba 50% of the area is affected negatively meaning that with high education is less adoption to manure. Soil erosion perception affects 99% of Yesir and 50% of Azuga-suba positively meaning that areas with erosion has high manure adoption probably due to the efforts of farmers in regaining soil fertility. This is contrary to Azuga-suba where erosion affects 50% negatively meaning that areas with erosion have low adoption as farmers do not want to risk the loss of manure to erosion. Access to extension affect Yesir negatively except for a small area in the south east. This means that the presence of extension discourages adoption of manure use. In Azuga-suba however, about 50% have positive effect of extension where extension encourages adoption of manure use. Access to markets in Yesir affects positively meaning that when a farmer has ease of access to market leads to high manure adoption. In Azuga-suba however, about 60% has access to markets affecting adopting negatively meaning that,when famers have ease of access to markets they do not use manure. This is due to the ease of access of inorganic fertilizers. Rainfall affects Yesir adoption to manure positively meaning that with high rain comes high adoption. In Azuga-suba however 70% of the area has a negative effect of rainfall implying that this part experiences low adoption when there is high rainfall. Slope affects Yesir in a lowly positive level, meaning that sloppy areas have high adoption to manure. In Azuga-suba, 50% have negative effect meaning sloppy areas experiences low adoption of manure. Credit access affects Yesir adoption positively meaning that there is high adoption of manure with access to credit. This is due to the ability to incur expenses related to manure use such as labour and transportation. In Azuga-suba, a 50-50% negative to positive effect is seen.

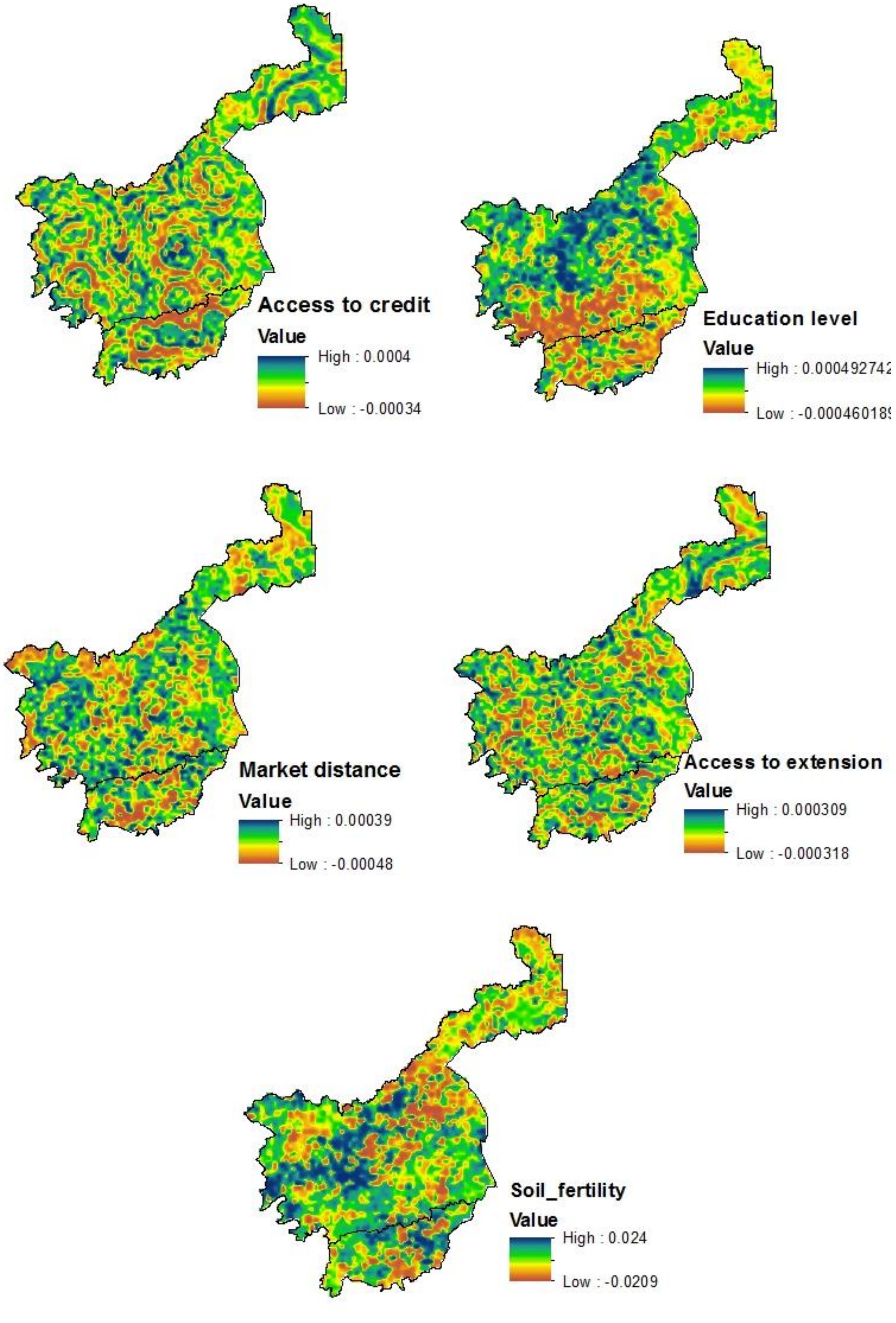

Figure 4.10: maps showing t-surface for the factors affecting the adoption of manure in western Kenya

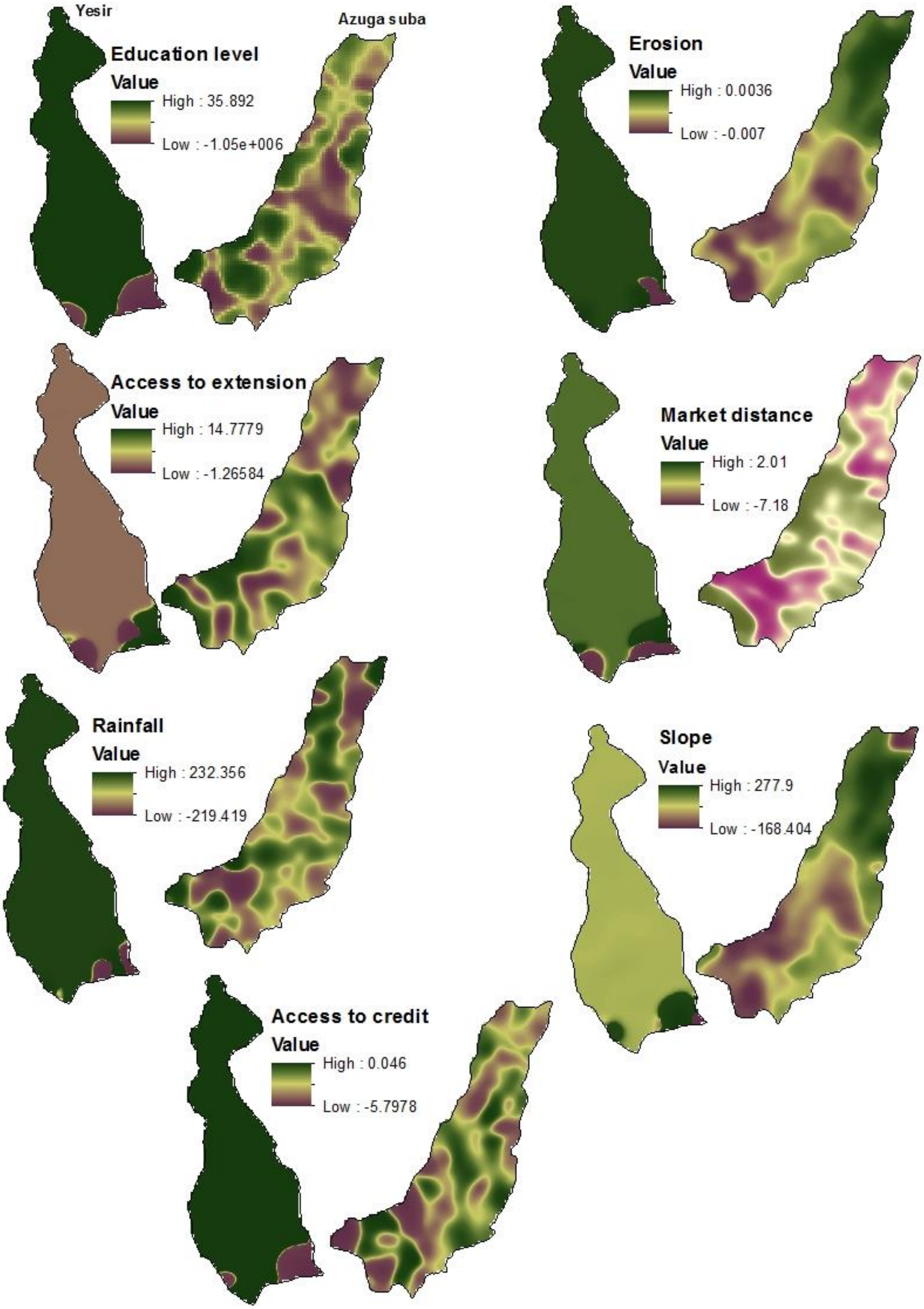

Figure 4.11: maps showing t-surface for the factors affecting the adoption of manure in Ethiopia

4.4.2.5 Residue management

The adoption to proper residue management in Kenya was affected by access to credit, education level, access to extension and soil fertility perception. In Ethiopia it was affected by level of education, soil fertility perception, access to extension, erosion, rainfall and plot slope. The t-surface for the driving factors is shown in figures 4.10 and 4.11.

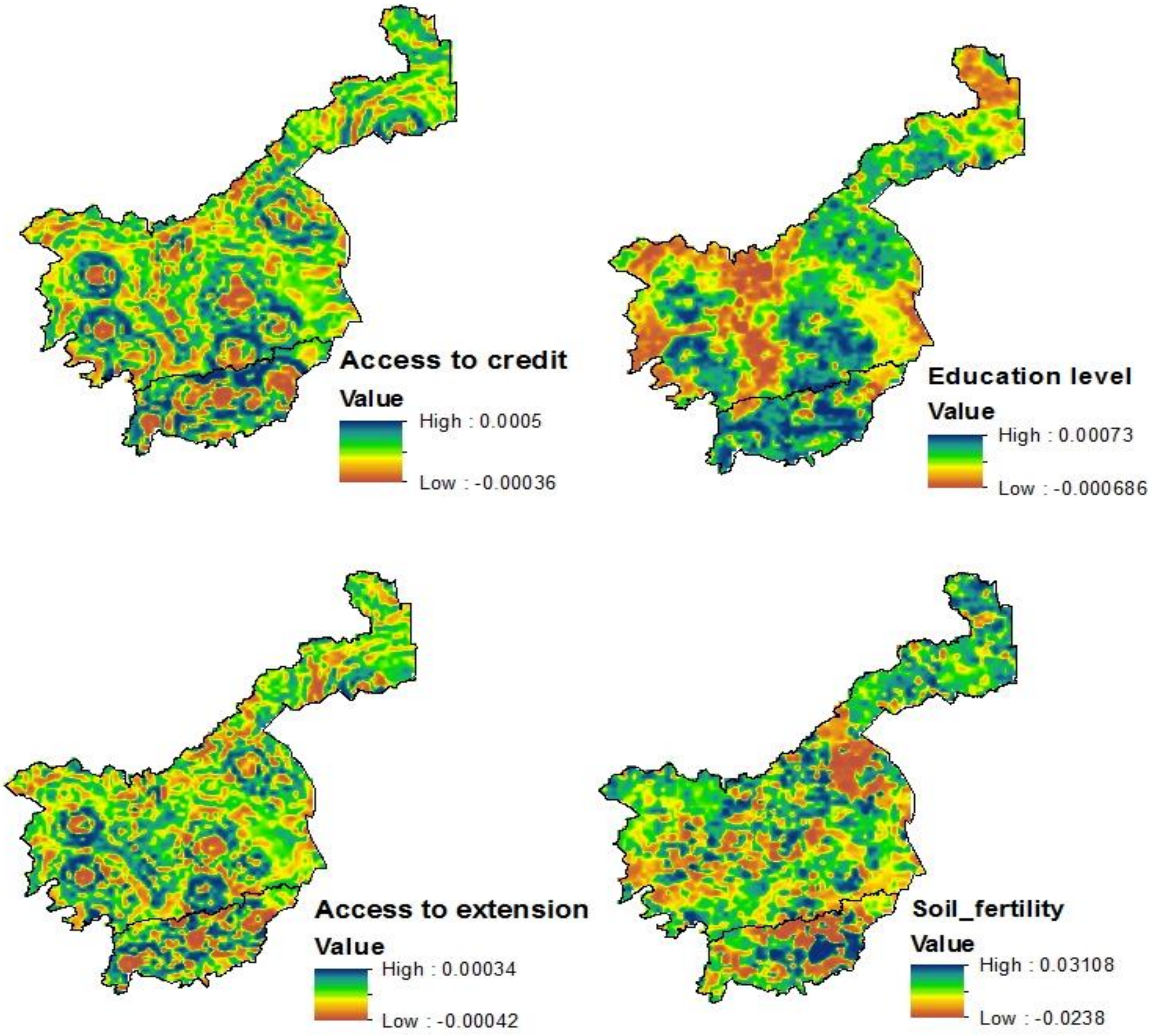

Figure 4.12: maps showing t-surface for the factors affecting the adoption of residue management in western Kenya

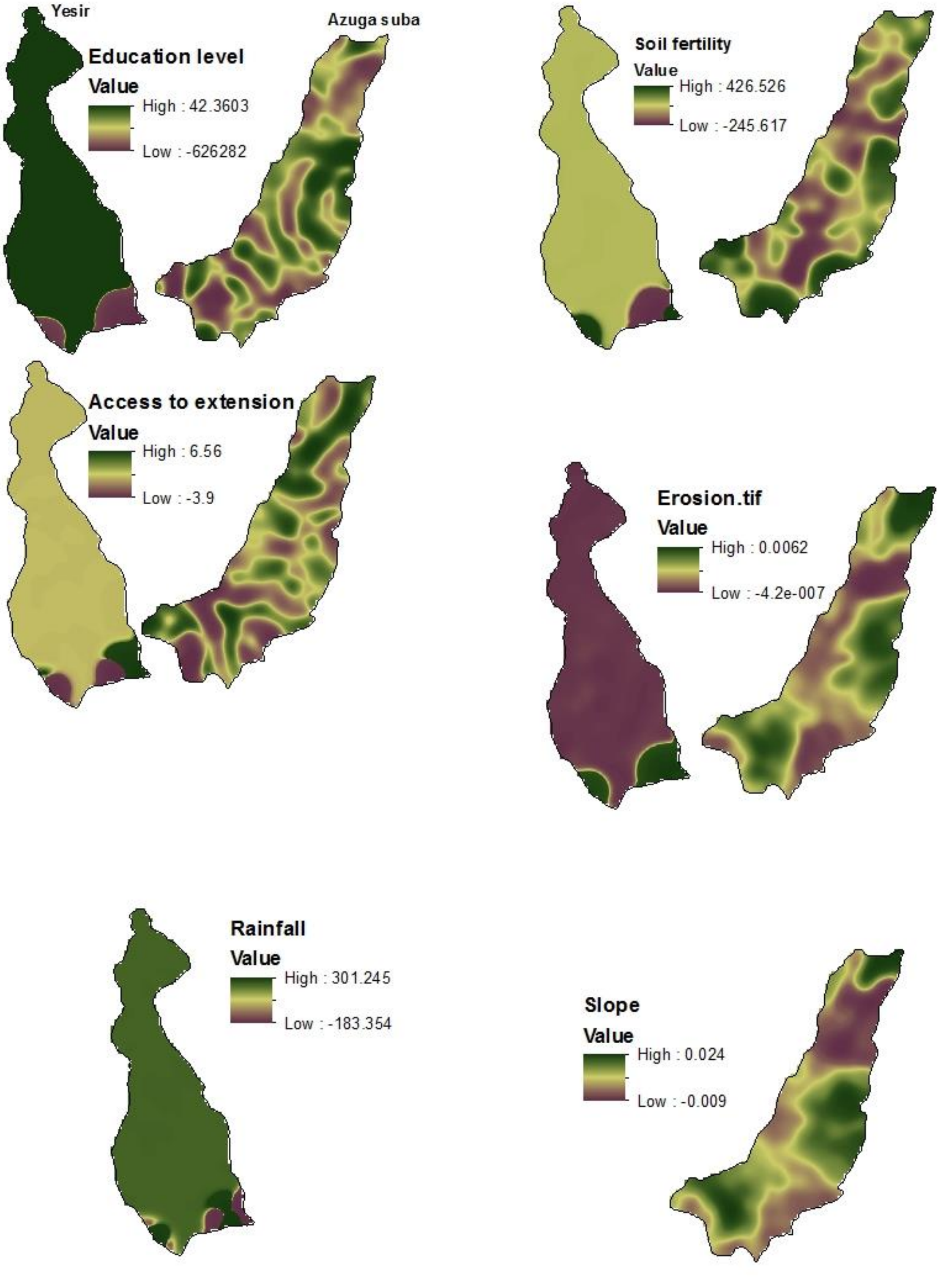

Figure 4.13: maps showing t-surface for the factors affecting the adoption of residue management in Ethiopia

In Kenya, access to credit affects the study area negatively in 50% meaning that with access to credit there is less adoption to proper residue management in these areas. 50% of the positively affected areas indicate that with access to credit is more adoption of proper residue management. Education on the other hand affects negatively the western side of Kakamega county as well as the north eastern and south eastern areas. This means that when the household heads are well educated, adoption is low. This can be attributed to the farmers having more knowledge of other soil carbon enhancing practices such as composting which requires the residues obtained on-farm. The compost manure is more ready as it is returned back to the farm. Other areas of Kakamega and 99% of Vihiga county show a positive effect where access to education leads to high adoption of proper residue management. Access to extension affects most of the study area positively meaning that with extension is high adoption. Soil fertility perception affects at least 50% of the study area positively meaning in these areas farmers who perceive their soil to be fertile adopt proper residue management. On the other hand, 50% of the area is affected negatively meaning that farmers who perceive their soil to be fertile do not adopt proper residue management.

In Ethiopia, education level affects at least 95% of Yesir and 40% of Azuga-suba positively. This means that with high education is more adoption of residue management. In Azuga-suba a 60% negative effect has been registered meaning that with high education comes less adoption probably due to more options for fertility management. Soil fertility perception affects at least 97% of Yesir and 40% of Azuga-suba meaning that with fertile soils is high adoption. In Azuga-suba a 60% negative adoption is seen meaning that with fertile soils is less adoption. Extension affects 97% of Yesir and of 40% Azuga-suba implying that with farmers with access to extension most probably adopt proper residue management. Contrary to 60% of Azuga-suba which shows negative effect. This means that with extension is less adoption. Soil erosion perception affects 94% of Yesir and 50% of Azuga-suba negatively to the adoption of residue management meaning that in eroded plots is less adoption. A 50% positive effect is registered in Azuga-suba meaning that in these areas, adoption increases with plot erosion. Rainfall is significant in Yesir where it affects adoption positively meaning that with high rainfall there is high adoption of residue management while slope was significant in Azuga-suba where it affects 50% of the area positively meaning that in these area, increase in slope leads to increased adoption and a 50% negative effect meaning that with increased slope there is less adoption.

4.4.2.6 Grass strips

The adoption of grass strips in Kenya was affected by access to credit, level of education, erosion, access to extension, slope and soil fertility perception while in Ethiopia, it was affected by access to credit, soil fertility perception, access to extension, distance to market, rainfall and plot slope.

In Kenya, access to credit services affects the study area adoption to grass strips, positively except the area around Kakamega forest. This means that with access to credit there is high adoption of grass strips. Access to education, slope and erosion perception affects adoption positively for the larger part of the study area. This means that with high education, high slope and high erosion leads to high adoption of grass strips (Kinama et al., 2007). Extension and soil fertility perception affects adoption of grass strips at a lower positive influence which means that when there is access to extension and the soil is fertile comes high adoption of grass strips.

In Ethiopia credit affects 98% of Yesir and 50% of Azuga-suba positively which means that with extension is more adoption of grass strips while 50% of Azuga-suba is affected negatively meaning with access to extension is less adoption. This can be attributed to extension giving other optionsin relation to the biophysical and socioeconomic characteristics of the area. Market access affects 95% of Yesir and about 40% of Azuga-suba positively meaning with ease of access to market is more adoption to grass strips. This can be attributed to ease of purchasing of grass seeds and other inputs. 60% of Azuga-suba is affected negatively meaning with ease of access to markets comes low adoption of grass strips probably due to other grass trade-offs provided by the market. Rainfall affects 98% of Yesir and 40% Azuga-suba positively meaning with more rainfall, there is more adoption to grass strips. Contrary to this 60% of Azuga-suba is affected negatively meaning with more rain is less adoption of grass strips. Slope affects 10% of Yesir and 60% of Azuga-suba positively. This means that with high slopes is more adoption of grass strips. Contrary to this, 90% of Yesir is affected negatively meaning that with high slopes is less adoption of grass strips.

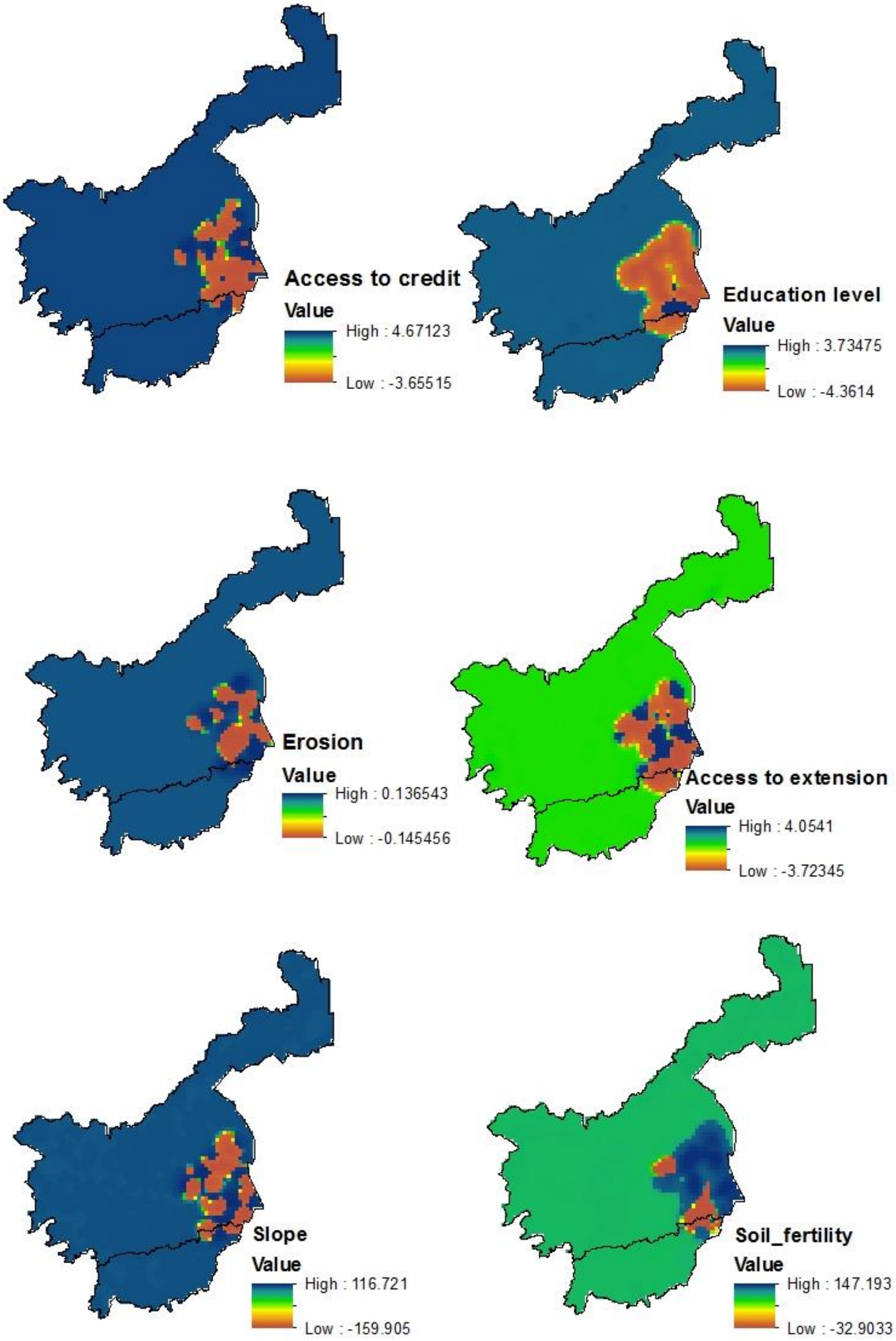

Figure 4.14: maps showing t-surface for the factors affecting the adoption of grass strips in western Kenya

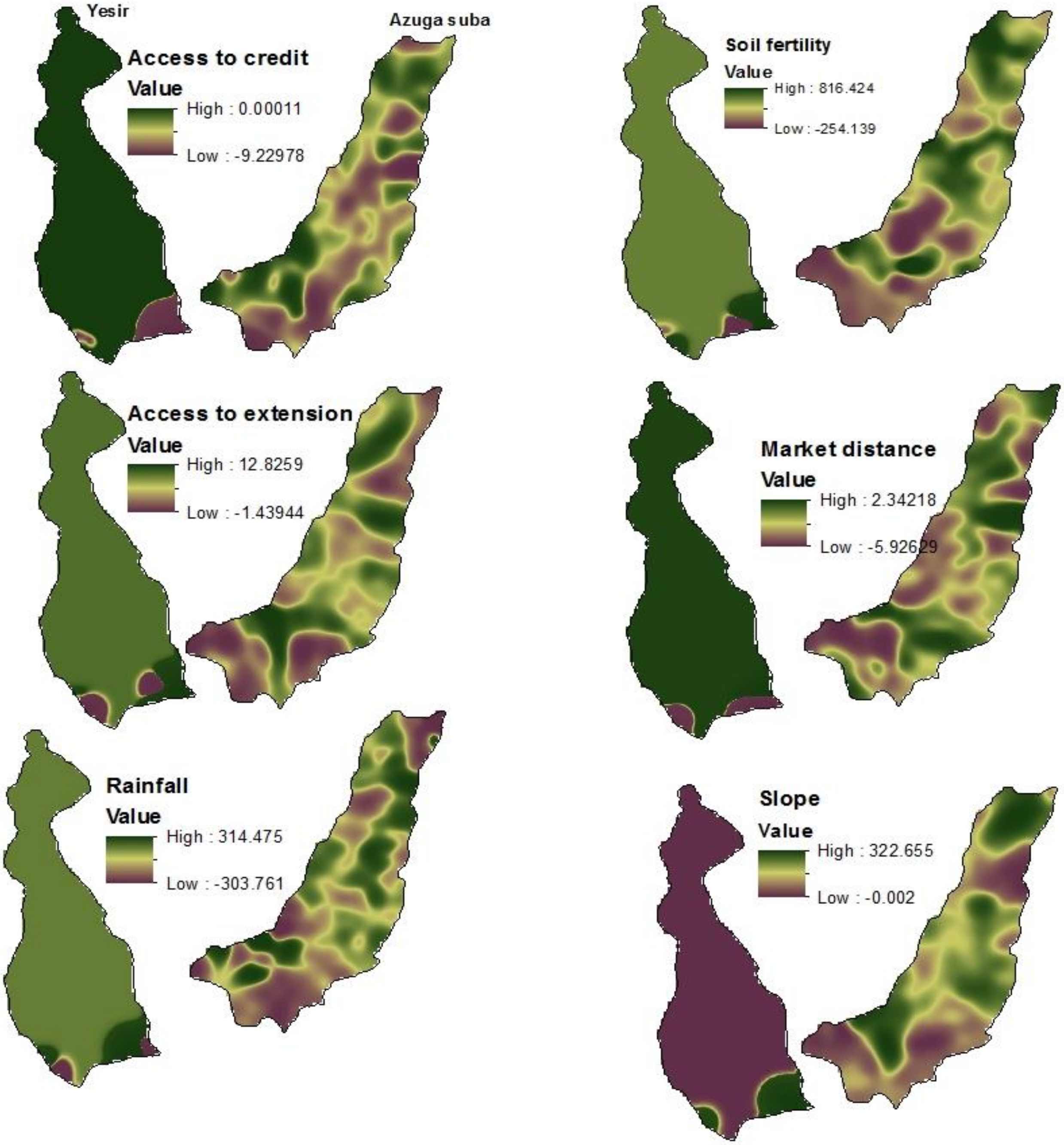

Figure 4.15: maps showing t-surface for the factors affecting the adoption of grass strips in Ethiopia

4.5 Conclusion and recommendations

Soil fertility perception, access to markets and plot slope are the major determinants of agroforestry adoption. This is because they show stronger positive relationships with agroforestry adoption in western Kenya. Hence increasing farmers' accessibility to markets –through provision of infrastructure such as markets and road networks will increase their accessibility to seeds and other inputs would lead to increase in adoption. Training farmers regularly on the importance of agroforestry in improving soil fertility and its role in controlling soil erosion and landslides on sloppy plots would be an effective way to improving agroforestry adoption in western Kenya. Fertilizer adoption in Kenya is mainly determined by access to credit, education level of the household head and access to extension. In Ethiopia, the major determinant to the adoption of fertilizer are education level of the household head, access to extension, access to markets and erosion perception. Therefore, improving the farmers' accessibility to credit which will improve their fertilizer purchasing power, providing farmers with proper training with training and demo plots and farmers field schools, providing an accessible and effective extension system, improving market accessibility and infrastructure and training farmers on effective ways of controlling erosion would be an effective way of ensuring that farmers apply fertilizers on their farmers. Intercropping in Kenya is majorly determined by education level of the household head and access to extension. Therefore, training farmers regularly and ensuring an accessible and a working extension system would be the best way in ensuring that intercropping is highly practiced in Western Kenya. Crop rotation in Ethiopia on the other hand, is mainly determined by education level of the household head, access to extension and soil erosion perception. Training of farmers, provision of a working extension system and proper soil fertility management training would lead to increased adoption of crop rotation in Ethiopia.

In Kenya, education level of the household head, access to extension, soil fertility perception are the major determinants of manure adoption. In Ethiopia on the other hand the major determinants are education level of the household head, soil erosion perception, access to markets and rainfall. Training of farmers in a regular basis together with the provision of an accessible and working extension system and provision of proper road networks and market infrastructure would be an effective method of improving the adoption of manure use in the fields of Kenya and Ethiopia. The major determinants of proper residue management adoption in Kenya and Ethiopia are, education level of the household head, access to extension and soil fertility perception. Training of farmers together with the provision of an accessible and working extension system would lead to increased adoption of proper residue management. The major determinants of grass strips adoption in Kenya are access to credit, education level of the household head, slope of the plot and soil erosion perception while in Ethiopia they are, access to credit, access to market and rainfall.

In a nutshell, encouraging farmer education so as to promote sustainable soil fertility management as well as improving the understanding of the biophysical and socioeconomic environment of smallholder systems can help target sustainable land management interventions aimed at enhancing SOC more appropriately. This will be enhanced by providing resources such as access to credit and affordable inputs.

CHAPTER FIVE

5.0 GENERAL CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study sought to assess the extent to which farmers have adopted soil organic carbon enhancing technologies (SOCETs). The results show that fertilizer use in both Kenya and Ethiopia is highly adopted at a maximum of 99%. This high adoption may be attributed by the ability of fertilizers to provide fast growth of crops and improve productivity as well by the ease of access of fertilizers attributed by provision of subsidized fertilizers. Manure adoption presents a 50% adoption in both Kenya and Ethiopia attributed to livestock ownership in these communities as well as education and advise obtained from extension staff on the use of organic manure. Intercropping presents an 80% adoption in Kenya while crop rotation presents a 44% adoption in Ethiopia. High adoption of intercropping in Kenya is attributed to the norm in practicing this technology across generations, the advantage of growing diverse crops in one farm and training obtained from extension officers. Crop rotation adoption on the other hand is attributed to training from extension officers. Grass strips adoption is at 30% in Kenya and Ethiopia. The adoption is attributed to training from extension on the control of soil erosion using grass strips as well as the requirements for fodder. Finally, residue management presents a 50% and 30% adoption in Kenya and Ethiopia respectively.

The study further sought to establish the socioeconomic and biophysical factors that constrains the adoption of SOCETs. the socioeconomic constraints include, tenure security, access to extension, access to credit services, access to input markets, farmer group memberships, household sizes and education level of the household heads. Lack of tenure security constraints the adoption of practices that require a long period of times to be profitable such as manure, agroforestry, residue management, grass strips and intercropping. Inability to access to extension services and low education level of the household heads leads to farmers being disadvantaged in terms of farming knowledge and knowledge of the advantages of SOCESTs. This constraints adoption. Inability to access markets and credit affects the adoption of technologies that requires capital for labour as well for purchase of inputs such as fertilizer, agroforestry, manure, intercropping and crop rotation. Plot size constraints the adoption of technologies that requires a lot of space calling for trading between growing food and adopting to the technology. Plot distance constraints the adoption of technologies requiring transportation of bulky inputs such as fertilizers and agroforestry. Being in farmer groups leads to increased knowledge of technologies giving farmers many options to choose from for their farms. The groups also form a haven for ease access of information, subsidized inputs and credit services.

The biophysical factors constraining adoption include rainfall, erosion and plot slope. Low rainfall constrains the adoption of technologies that require rain to be effective such as manure and fertilizer failure to which the inputs could lead to scorching of crops. On the other hand, high rainfall in plots with high slopes leads to erosion and this discourages the adoption of technologies that are at a risk of getting lost to soil erosions such as manure, fertilizers and residue management.

Finally, the study sought to establish a spatial relationship between adoption of SOCETs and the factors affecting adoption of SOCETs and representing the magnitude by which each factor affected the adoption of each SOCET. Study shows that the influence of factors affecting the adoption of SOCETs vary greatly across space with one factor affecting adoption in one part of the study areas at a high impact to the positive while at the same time the same factor affecting another part of the area mildly positive, mildly negative or highly negative. This is due to the fact that areal characteristics vary across geographical areas. The areas will have different socioeconomic and biophysical factors affecting farmers' adoption of SOCETs and this will result into different choices to the adoption of SOCETs.

5.2 Recommendations

The study recommends that encouraging farmer education so as to promote sustainable soil fertility management as well as improving the understanding of the biophysical and socioeconomic environment of smallholder systems can help target sustainable land management interventions aimed at enhancing SOC more appropriately. This will be enhanced by providing resources such as access to credit and affordable inputs.

For the researchers carrying similar studies on factors affecting adoption of SOCETs, the study recommends incorporating the geographical aspect into investigating these factors. This is because the magnitude and direction into which these factors affect the choices of farmers vary spatially.

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APPENDICES

Appendix A: Probit model regression results for the variables that affect the probability of adoption in western Kenya

	Manure							Intercropping
	Kisa West	Butsotso South	Manda-Shivanga	Mayoni	N.E Bunyore	Gisambai	South Maragoli	Shirere
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
					2.986***			
	2.278***				0.933		-3.825***	
Tenure security	0.788						1.238	
		-0.010***		0.024***			0.029***	
Distance to market		0.004		0.008			0.009	
	-2.594***							
Access to extension	0.687							
	-3.479***	-0.497*					2.256***	
Plot size	1.234	0.290					0.810	
	1.264**	-1.569***	-2.221**	1.987**			2.165**	
Plot fertility	0.627	0.597	0.874	0.781			0.919	
		0.344**	-0.702***					
Household size			0.251					
					-0.107***			
		0.061***	0.069*	-0.13***	0.031		-0.147***	
Farming experience		0.019	0.037	0.042			0.036	
		-1.655**				-0.874*	2.142**	
Farmer groups membership		0.699				0.536	1.073	
					-1.055***			
		0.441**			0.399	-0.393*	-0.747*	
Education level		0.214				0.226	0.446	
				-0.081***				
Distance to plot				0.031				
							-4.757***	
Access to credit							1.487	
							-0.009**	6.523*
Annual rainfall							0.005	3.643

Note. *p < 0.10, **p < 0.05, ***p < 0.01. The standard error is at the bottom of the coefficient. $N = 334$ $n_{plots}=1027$

.	**Inorganic fertilizer**	**Residue management**		**Grass strips**		**Agroforestry**		
	Gisambai	Kisa West	Butsotso South	Kisa West	Mayoni	Butsotso South	Manda-Shivanga	Shirere
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
	-2.448**				1.850***			
Tenure security	1.008				0.646			
	-0.075**				0.016***			
Distance to market	0.030				0.005			
			1.259**		-1.357**			
Access to extension			0.602		0.674			
Plot size								
		1.038**			-2.409***	-1.876**		
Plot fertility		0.418			0.673	0.907		
	-0.547***							
Household size	0.192							
	0.132***				-0.081**	0.058*		
Farming experience	0.049				0.032	0.030		
	-3.407**		-1.052*		1.975*			
Farmer groups membership	1.829		0.636		1.049			
	1.944***				-1.169***	0.656*		
Education level	0.714				0.413	0.364		
Distance to plot								
					-1.730***	1.080**		
Access to credit					0.638	0.660		
				-0.042***			36.6***	
Annual rainfall				0.012			1.728	

Note. *p < 0.10, **p < 0.05, ***p < 0.01. The standard error is at the bottom of the coefficient. $N= 334$ $n_{plots}=1027$

Appendix B: Probit model regression results for the variables that affect the probability of adoption in Ethiopia

	Manure								**Crop rotation**			
	Ambercho Wasere	Bondenna	Bucha	Gerba Findide	Gulim	Jib Gedel	Tengeha	Wadra	Gulim	Jib Gedel	Tengeha	Wadra
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
Tenure security					1.663*** 0.389	0.485** 0.203	0.720** 0.310	1.037*** 0.245	-1.24*** 0.381	-0.390** 0.181		0.832*** 0.283
Distance to plot	-0.198*** 0.064		-0.072** 0.028	-0.089*** 0.029		0.040** 0.018	-0.044*** 0.012			0.020* 0.011		-0.03*** 0.009
Distance to market	0.048*** 0.012			-0.057*** 0.010	-0.035*** 0.006	0.006* 0.004	-0.073*** 0.019	0.005*** 0.003	0.038*** 0.007	-0.02*** 0.003	-0.015* 0.008	-0.02*** 0.005
Slope of the plot	-0.4*** 0.104	-0.159** 0.074		-0.08** 0.041	1.49*** 0.200		0.86** 0.351	0.77*** 0.296	0.68*** 0.151	-0.16*** 0.031		0.337*** 0.095
Access to extension	-2.225*** 0.618					0.661*** 0.202		2.506*** 0.332		-0.314* 0.190	-0.88*** 0.262	
Education level	0.329* 0.178											
Household size	0.206** 0.105	-0.375*** 0.067	-0.565*** 0.099	0.426*** 0.133	0.184*** 0.058		0.42*** 0.109		0.301*** 0.084	0.104* 0.056	0.118* 0.065	-0.137** 0.080
Farming experience	0.079*** 0.025			-0.041** 0.020			-0.049*** 0.017		0.06*** 0.012	-0.01* 0.007		-0.04*** 0.012
Access to credit					0.401** 0.195				0.902*** 0.261			0.677* 0.266
Farmer groups membership	1.307* 0.786			-1.926*** 0.681		-0.979*** 0.199	4.45*** 0.760				-0.75*** 0.221	
Soil erosion	1.124*** 0.389	-1.066*** 0.221				-0.458** 0.183	-0.706* 0.374		-0.497* 0.271		1.334*** 0.328	
Plot size						-2.727** 1.369	7.602*** 2.259		-0.55** 0.232	-3.6*** 1.263		-3.47** 1.548
Annual rainfall	0.121*** 0.040		0.133*** 0.020	0.086*** 0.021	-0.557*** 0.214		-0.351*** 0.071	0.082*** 0.017	-0.38*** 0.045	0.017*** 0.003	0.041** 0.021	
Plot fertility		-0.720*** 0.265	-0.919*** 0.324		0.058*** 0.014		-1.220** 0.492		1.437** 0.720	-0.567** 0.227	-0.830** 0.390	
Livestock ownership						2.196*** 0.400						

Note. *p < 0.10, **p < 0.05, ***p < 0.01. The standard error is at the bottom of the coefficient. $N = 380$ $n_{plots} = 2610$

	Residue management								**Grass Strip**				
	Ambercho Wasere	Bondenna	Bucha	Gerba Findide	Gulim	Jib Gedel	Tengeha	Wadra	Ambercho Wasere	Bondenna	Bucha	Gerba Findide	Gulim
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
Tenure security		-1.168**	3.431**						1.544***				
		0.597	1.349						0.492				
Distance to plot	0.038**		0.334***		0.004**	-0.024**		-0.02**	0.071***				-0.13***
	0.015		0.127		0.002	0.012		0.012	0.019				0.040
Distance to market	-0.006*	-0.031*	-0.049***		-0.005**	0.007**			0.009**			-0.007*	-0.08***
	0.004	0.017	0.016		0.002	0.003			0.004			0.004	0.022
Slope of the plot		-0.417***			0.200**	0.060**			-0.123***			0.036*	
		0.110			0.097	0.029			0.031			0.021	
Plot size	1.656***	-4.559***	-8.932**	1.047***	0.339*	-3.216**		-4.5**		-3.83***	-3.6***		
	0.509	1.589	4.544	0.290	0.185	1.377		1.965		1.100	1.377		
Household size	0.103***	-0.586***		-0.188***			0.3***		-0.12***			-0.13***	2.205***
	0.039	0.105		0.049			0.122		0.045			0.046	0.639
Farming experience				0.028***	-0.02***				-0.024**				
				0.011	0.007				0.010				
Farmer groups membership	-2.917***	-1.008*		-0.880***	1.536***	0.458***	1.5***	-1.1***	1.163***			-0.9***	
	0.676	0.525		0.245	0.517	0.177	0.373	0.297	0.289			0.247	
Access to credit				-0.812**	-0.4***		-0.7**		-1.643***			1.12***	
				0.336	0.157		0.290		0.504			0.300	
Plot fertility	0.694**								1.548***				
	0.286								0.352				
Soil erosion	0.423**	-1.819***	2.169***			-0.6***			0.417**	0.420*	0.67***		
	0.197	0.471	0.835			0.183			0.206	0.247	0.246		
Education level			-0.178*	0.071***	0.036*			-0.063*					0.408***
			0.096	0.023	0.018			0.034					0.128
Annual rainfall			-0.480***	0.030**	-0.1***	-0.004*			0.019*	0.105*	-0.1***	-0.03***	-0.204*
			0.157	0.013	0.013	0.002			0.010	0.055	0.014	0.012	0.123
Access to extension				-0.585***					-1.36***			0.71***	
				0.222					0.248			0.196	

Note. *p < 0.10, **p < 0.05, ***p < 0.01. The standard error is at the bottom of the coefficient. $N= 380$ $n_{plots}=2610$

Inorganic fertilizer

	Ambercho Wasere	Bondenna	Gerba Findide
	Coef.	Coef.	Coef.
Distance to plot	1.279*** 0.403		
Distance to market	0.049*** 0.015	-0.024* 0.014	0.029*** 0.007
Slope of the plot	-0.435*** 0.116	-0.285*** 0.110	-0.086* 0.046
Access to extension	-1.685*** 0.572		
Plot size	4.991** 2.887	-3.244*** 0.666	1.882*** 0.662
Household size	0.316** 0.163		-0.166*** 0.064
Plot fertility	2.833*** 0.633		0.842* 0.483
Soil erosion	2.771*** 0.834	-0.465* 0.259	
Annual rainfall	-0.113*** 0.035	-0.199*** 0.070	
Farming experience		0.061*** 0.019	

Note. *p < 0.10, **p < 0.05, ***p < 0.01. The standard error is at the bottom of the coefficient. $N= 380$ $n_{plots}=2610$